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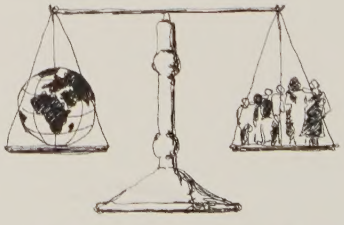

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Physical weed control in processing tomatoes in Central Italy

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Abstract

Tomato is a very important vegetable crop in Italy. Improving the means of production for processing organic tomatoes could help guarantee better profits for farmers and, at the same time, enhance environmental management and safeguard consumers' health. Weed control, in particular within crop rows, is one of the main problems in organic farming, and thus also for the organic cultivation of tomato. The aim of this study was to develop innovative strategies and equipment for effective physical weed control in processing tomatoes. A conventional weed management system incorporating herbicides was compared with an alternative system relying exclusively on physical control during three growing seasons (2006–2008) on a farm located near Pisa, Italy. The crop was transplanted mechanically onto paired rows. The conventional strategy consisted of three different chemical treatments, two post-transplanting PTO-powered rotary hoe passes and several hand-weeding treatments on the paired rows. The alternative system included a stale seedbed technique (performed by a rolling harrow pass and one flaming treatment), two post-transplanting precision hoeing treatments and several hand-weeding treatments. All the machines for the alternative system were adjusted and set up for processing tomatoes transplanted in paired rows. Each physical treatment (mechanical and thermal) within the alternative system allowed an 'instantaneous' (just before/just after) weed control from 50 to 100%, while the alternative strategy as a whole achieved values of weed dry biomass at harvest ranging from 22 to 126 g m^{-2}. However, the alternative system required a total labor input that averaged 50% higher than the conventional strategy. The conventional system had on average more effective weed control than the alternative system, but both strategies controlled weeds effectively. Weed biomass at harvest averaged 36 and 68 g m^{-2} for conventional and alternative strategies, respectively. On the other hand, the alternative system generally led to a significant increase in fresh crop yield (+13% average yield for the 3 years).

Key words: flaming machine, rolling harrow, precision hoe, stale seedbed technique

Introduction

In Italy, tomato is an important vegetable crop. From 2006 to 2008, there was a significant reduction in agricultural areas in Italy dedicated to tomato production (from 103,254 to 92,842 ha)[1]. This was mainly due to political reasons [uncertainty regarding Common Market Organization (CMO) for Fruit and Vegetables reform[1]] and financial reasons (high-production fixed costs)[2]. Poor spring yields of early tomatoes in northern Italy in 2008, along with a fall in cereal prices[3], resulted in high prices paid for tomato that year and an increase in the harvested area of tomatoes to approximately 98,000 ha[1] in 2009. This increased production of tomatoes could cause a reduction in subsidies as a result of the new system adopted by the Common Agricultural Policy, with negative consequences on the profitability of both tomatoes and cereals in Italy[4]. In this context, the organic production of tomatoes could help by providing better profits for farmers and, at the same time, protecting the environment and safeguarding consumers' health.

The characteristics and the quality of an agricultural product are affected by several factors, including the system of farm production[5]. There is still debate on the difference between organic and conventional products in terms of quality and nutritive value[6]. Research has shown

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Figure 1. Tomato field near Pisa, Italy in 2007 showing paired rows with the drip line in place. Spacing between the paired rows (center to center) is 150 cm, spacing between the two rows in each pair is 40 cm and spacing between plants within a row is 40 cm.

that organically grown produce has a higher mineral, vitamin and antioxidant content than conventionally grown produce[7–11]. In addition, the antioxidant content of food obtained using organic production methods may be more bioavailable for human health[8]. A study on the factors affecting food choice with respect to fruit and vegetable intake has also proved that personal ideologies are essential in consumer choice, and this explains the increase in sales of organic products, despite their higher cost[12].

Weed control, in particular within crop rows, is one of the main problems in organic farming[13], including organic processing tomato. Some researchers in Spain evaluated the effectiveness of various cultivation equipment and mulches on tomato[14–16]. According to these authors, the timing of mechanical treatment is a key factor in order to obtain good weed control[14–16], and perennial weed species with rhizomes, such as *Cyperus rotundus*, are very difficult to control with this kind of equipment[14–16]. However, the authors maintain that good control of this 'problematic weed' can be achieved with brown kraft paper mulching[15], and moreover the presence of the drip line can hinder mechanical control[14].

Growing tomatoes in paired rows is a popular practice in Italy, and is preferred over evenly spaced rows in central areas of the country[17]. Fruits tend to ripen more uniformly when plants are arranged in paired rows[17], and the need for only one irrigation line for paired versus equally spaced rows simplifies general field practices and reduces costs[17]. However, physical weed control in paired rows can be difficult because of the irrigation hose between the two rows in the narrow inter-row space. Our objective was to develop weed control strategies for processing tomato that relied exclusively on physical control methods.

Materials and Methods

The experiment was conducted during three growing seasons (2006–2008) at a conventional farm located near Pisa, Italy (+43°46′14.04″ +10°23′3.83″), on sandy-loam soil (sand 60%, silt 22%, clay 18%, organic matter 1.7% and pH 8.2). Tomatoes were grown in a 4-year tomato–wheat–maize–sunflower rotation.

Two tomato hybrids were used: 'Leader' in 2006 and 'Reflex' in 2007 and 2008. Leader F1 is a mid-season hybrid that produces joint-less fruit (mean weight = 80 g) with thick, deep-red walls that are recommended for dicing and paste. Reflex F1 is an early hybrid that produces oval-blocky, joint-less, fruit (mean weight = 85 g) which are firm and fleshy and recommended for both dicing and paste.

The crop was transplanted mechanically into paired rows at a density of 33,000 plants ha^{-1}, with a 1.1 m distance between adjacent pairs, 0.4 m distance between the rows within the pair and 0.4 m in-row spacing between plants (Fig. 1). The crop was irrigated by drip hoses placed between pairs at an average rate of 2900 $m^3 ha^{-1} yr^{-1}$. Organic–mineral fertilizer was broadcasted before crop planting at 1.2 Mg ha^{-1} 'Organagro' (N-P-K 5-5-2). Post-transplanting fertilizers consisted of 41 kg ha^{-1} N as 100 kg ha^{-1} of urea-based fertilizer, 45 kg ha^{-1} P_2O_5 as

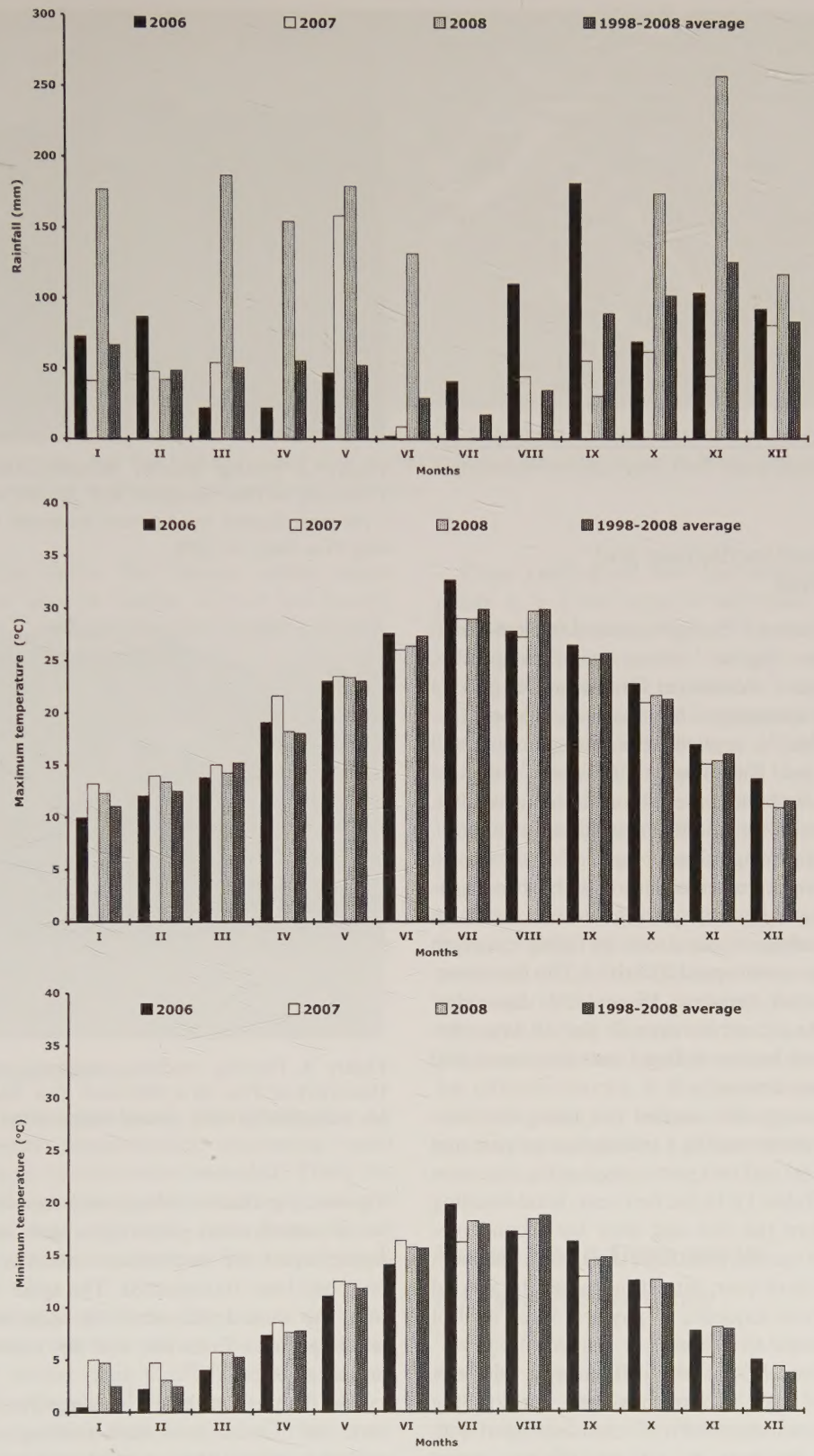

Figure 2. Climatic data recorded in the municipality of San Giuliano Terme (Pisa, Italy) in 2006, 2007, 2008 and 20-year (1998–2008) averages: total monthly rainfall values (upper panel), average monthly maximum temperature values (middle panel) and average monthly minimum temperature values (lower panel).

150 kg ha^{-1} of concentrated superphosphate, 25 kg ha^{-1} K_2O as 50 kg ha^{-1} of potassium sulphate and 100 kg ha^{-1} of ternary fertilizer (21-21-21). Total seasonal (March–August) rainfall and temperature followed the long-term average of the area during 2006 and 2007, while 2008 was particularly wet (Fig. 2).

Table 1. Time sequence of the different treatments carried out on processing tomato for the physical weed control management for the 3-year experiment (2006–2008) near Pisa, Italy.

	Timing (days)					
	2006		2007		2008	
Treatments	**DBT**	**DAT**	**DBT**	**DAT**	**DBT**	**DAT**
Rolling harrowing	13	–	10	–	8	–
Flame weeding	1	–	1	–	1	–
First hoeing	–	20	–	20	–	19
Second hoeing	–	40	–	44	–	42
Hand weeding	–	18	–	60	–	55
Hand weeding	–	59	–	–	–	68
Hand weeding	–	–	–	–	–	80

DBT, days before transplanting; DAT, days after transplanting.

Figure 3. Rolling harrow, designed and developed at the University of Pisa, equipped with flexible teeth and used during a pre-transplanting weed control treatment on processing tomato near Pisa, Italy, in 2008.

Figure 4. Flaming machine, designed and developed at the University of Pisa, in a field near Pisa, Italy, in 2008 during a pre-transplanting weed control treatment on processing tomato.

Weed management techniques and operating machines

Conventional weed control strategy included three different herbicide treatments: 1 kg ha^{-1} Stomp (a.i. Pendimetalin, 317 g ha^{-1}) and 1 kg ha^{-1} Ronstar (a.i. Oxadiazon, 341 g ha^{-1}) applied before transplanting, 250 g ha^{-1} of Sencor (a.i. Metribuzin, 87.5 g ha^{-1}) applied after transplanting and 40 g ha^{-1} of Titus (a.i. Rimsulfuron, 10.0 g ha^{-1}) applied after transplanting. Herbicides were broadcasted using flat, anti-drift spray nozzles at 0.2 MPa in solution at approx. 500 litres ha^{-1} using a Barigelli self-propelled applicator. In the conventional weed management system, two post-transplanting, PTO-powered rotary hoe treatments were also performed between adjacent paired rows by tilling to a depth of 7 cm at an average travel speed 2 km h^{-1}. The first rotary hoeing was conducted between 15 and 20 days after transplanting, and the second between 35 and 40 days after transplanting. Several hand-weeding treatments were also performed on the paired rows.

The physical strategy was carried out using the stale seedbed technique (performed by a rolling harrow pass and one flaming treatment) and two post-transplanting precision hoeing treatments (Table 1). In the first year, hand-weeding was performed before the first and after the second precision hoeing; in the second year, after the second precision hoeing; and, in the third year, three times after the second hoeing. The exact time sequence of physical weed control management is reported in Table 1.

The equipment used for the physical strategy was built at the University of Pisa. A 2-m maximum wide rolling harrow[18] (set with a working width of 1.5 m) equipped with flexible tines was designed to provide effective weed control both by creating a false-seedbed and in precision hoeing after crop transplanting. The machine consisted of spike discs in the front and cage rolls at the rear of the unit (Fig. 3). The discs and rollers were inserted into two axles, connected by means of a chain drive with easily adjustable gear ratios. The discs and cage rolls were placed close together for shallow tillage and non-selective mechanical weed control when preparing a stale seedbed, and spaced further apart for mechanical inter-row weeding after the crop had been transplanted. The spike discs tilled the soil to a 3 to 4 cm depth, while the cage rolls separated weed seedling roots from the soil by rotating with a higher peripheral speed[18–20].

The flaming machine[21] was equipped with three 50-cm wide rod burners, for a total working width of 1.5 m, connected to three 15 kg liquefied petroleum gas (LPG) tanks placed in a hopper (Fig. 4). A heat exchange system used the exhaust gas from the tractor endothermic engine to prevent the tanks from cooling during flaming. Each LPG tank was equipped with a pressure regulator and a manometer and was connected to a control system. The control system of each burner consisted of two manual valves and

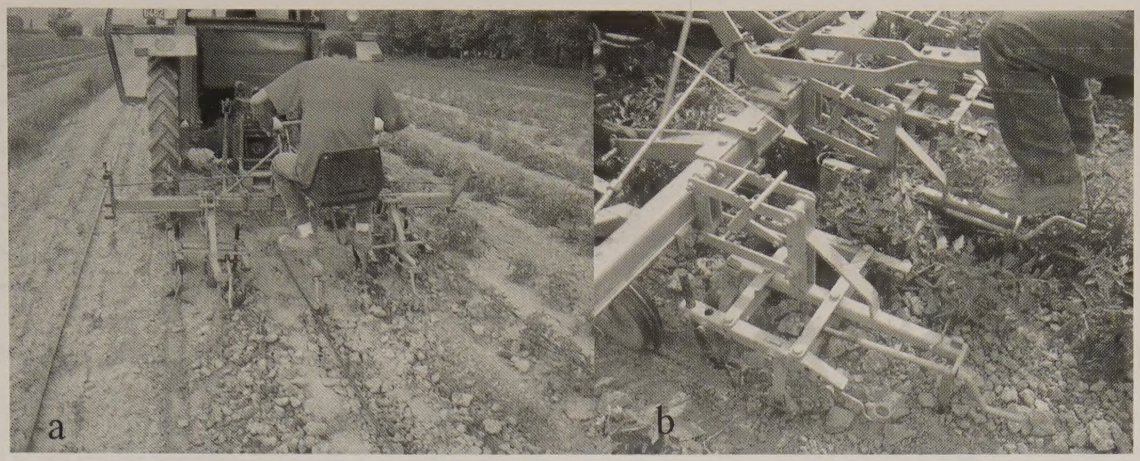

Figure 5. (a) Early precision hoeing treatment performed, with a machine designed and developed at the University of Pisa, in processing tomato without removing the drip line between paired rows in 2007; (b) late precision hoeing in 2006. The hoe was equipped with 'V'-shaped elements in order to open the developed crop vegetation.

one automatic safety valve. The manual valves enable the LPG feed to be adjusted (closed, high or low levels). The automatic safety valve was connected with a thermocouple located inside the burner, which closes the LPG feed if the flame goes out.

The precision hoe was 1.5 m wide and consisted of a central goose-foot sweep and two side 'L'-shaped sweeps along with flexible tines for intra-row selective weed control[20,22,23]. A steering handle was used to adjust the position of the working tools. Weeds were controlled by using the precision hoe inside the crop-paired rows, with the drip line in place (Fig. 5a). The precision hoe had a 'V'-shaped crop protector for gently opening the tomato vegetation during late hoeing and preventing damage to vegetable plants (Fig. 5b).

Experimental assessments

Machine and yard operational characteristics. All the main operational characteristics concerning weed management for both systems were recorded. These included tillage depth, operating speed, working productivity, operating time, fuel and LPG consumption for all equipment used, and labor requirements for manual weeding.

Weeds. Weed density was recorded before and after each physical weed control treatment by counting the number of weeds within three $0.25\,m \times 0.3\,m$ quadrants within each $1.5\,m \times 50\,m\,plot^{-1}$. Quadrants were oriented following the row direction, with one placed in the inter-row space between paired rows, one placed within a single row and one placed between two pairs. At tomato harvest, weed samples were collected from two $1.5\,m \times 0.8\,m$ quadrants oriented in the perpendicular direction to the rows across a row pair in each plot. Weed samples were oven dried until constant weight and the biomass was reported on a $g\,m^{-2}$ dry weight basis.

Crop yield. Fruit was harvested manually from four plants in a $1.2\,m^2$ area in each plot. Marketable tomato yield was reported in $Mg\,ha^{-1}$. At harvest, measurements were performed on four sample units of $1.2\,m^2$ area $plot^{-1}$ to evaluate the marketable tomato yield.

Experimental, sample design and statistical analysis. Weed strategy treatments were arranged in a randomized complete block and replicated four times. Weed and tomato yield data were subject to analysis of variance using CoStat software (CoHort Software version 6.311). Weed density data were transformed according to the square root function before the analysis, but presented in back-transformed values. Weed biomass and yield were assessed using the block sampling design, a technique in which all the plots of the same block (i.e., replication) are subjected to the same randomization scheme (i.e., using the same sample location in the plot) and different sampling schemes are applied separately and independently for different blocks. A Bartlett test was performed to test the homogeneity of variance. Treatment means were separated using a protected LSD test at $P \leqslant 0.05$.

Results and Discussion

Equipment performance

The performance of the rolling harrow was consistent over the 3 years. The harrow tilled soil to an approximate 3 cm depth and consumed roughly $3\,kg\,fuel\,ha^{-1}$. A relatively high speed ($>6.4\,km\,h^{-1}$) minimized operating times ($<1.34\,h\,ha^{-1}$). In each of the 3 years fuel consumption was approximately $3\,kg\,ha^{-1}$ (Table 2). The flaming treatment was applied at a ground speed of $3.5\,km\,h^{-1}$ ($2.08\,h\,ha^{-1}$) and operating pressure of 0.2 MPa with an LPG consumption of roughly $20\,kg\,ha^{-1}$. Precision hoeing was applied at a ground speed ranging from $2.5\,km\,h^{-1}$ ($3.03\,h\,ha^{-1}$) to $1.2\,km\,h^{-1}$ ($5.9\,h\,ha^{-1}$),

Table 2. Performance of the machines used for physical weed control and hand weeding working time in the 3 years of experiment (2006–2008) in processing tomato near Pisa, Italy.

Treatment	Working depth (cm)			Working speed (km h^{-1})			Working productivity (ha h^{-1})			Working time (h ha^{-1})			Operators			Fuel consumption (kg ha^{-1})		
	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Rolling harrowing	3.5	2.8	2.8	6.8	6.4	6.5	0.90	0.75	0.85	1.11	1.34	1.18	1	1	1	3.3	3.1	3.2
Flaming	–	–	–	3.4	3.5	3.5	0.49	0.48	0.48	2.23	2.08	2.08	1	1	1	6.5	5.9	6.6
Precision hoeing 1	2.9	2.7	2.7	2.5	1.4	1.9	0.33	0.20	0.27	3.03	5.11	3.69	2	2	2	8.1	13.2	11.5
Precision hoeing 2	4.7	3.5	4.2	1.3	1.2	1.4	0.18	0.17	0.20	5.48	5.90	5.06	2	2	2	14.8	15.3	15.7
Hand weeding (total)	–	–	–	–	–	–	–	–	–	33.70	16.60	40.00	–	–	–	–	–	–

Working width was equal to 1.5 m for all the experiment; tractor engine capacity was always equal to 55.0 kW in 2006, 44.2 kW in 2007 and 58.3 kW in 2008.

Table 3. Total labor hours for weed control for two different weed control strategies carried out in processing tomato near Pisa, Italy (2006–2008).

Weed management system	Labor (h ha^{-1})		
	2006	2007	2008
Conventional	15.0	11.3	50.0
Physical	54.1	42.0	61.0

Table 4. Weed density recorded before each physical treatment for two different weed control strategies carried out in processing tomato near Pisa, Italy (2006–2008). In each row, means followed by the same letter are not significantly different at $P \leqslant 0.05$.

Year	Survey period	Weed density (plant m^{-2})	
		Physical strategy	Conventional strategy
2006	13 DBT	16 a	10 a
	1 DBT	51 a	6 b
	20 DAT	68 a	1 b
	40 DAT	46 a	3 b
2007	10 DBT	4 a	2 a
	1 DBT	2 b	4 a
	20 DAT	35 a	5 b
	44 DAT	9 a	2 a
2008	8 DAT	301 a	303 a
	1 DBT	17 a	6 a
	19 DAT	77 a	14 b
	42 DAT	49 a	2 b

DBT, days before transplanting; DAT, days after transplanting; letters indicating differences between mean weed density values (actual values) were computed using square root-transformed data.

depending on the operational conditions. The depth of soil tilled by precision hoeing was always shallower at the first date (2.8 cm average) than at the second date (4.1 cm average). Fuel consumption averaged 13 kg ha^{-1} for each hoeing.

The performance of the precision hoe indicated that it was particularly suited to the crop and its spatial arrangement. Total operating time for practices included in the physical weed control strategy totaled 40–60 h ha^{-1}, depending on the year (Table 3). This range in time reflected differences in the amount of hand weeding that occurred. Hand weeding was done twice totaling 33.7 h ha^{-1} in 2006, once totaling 16.6 h ha^{-1} in 2007 and three times totaling 40 h ha^{-1} in 2008. The conventional weed control strategy had lower labor requirements in each of the 3 years. Differences in labor needs between the two strategies were least in 2008 because of generally wet conditions, creating optimal climatic conditions for weed growth and timely application of other weed control measures.

Table 5. Table yield and weed biomass at harvest (2006–2008) for two different weed control strategies carried out in processing tomato near Pisa, Italy. In each column and year, means followed by the same letter are not significantly different at $P \leqslant 0.05$ (LSD test).

	Yield (Mg ha^{-1})			Weed dry biomass (g m^{-2})		
Weed management system	**2006**	**2007**	**2008**	**2006**	**2007**	**2008**
Conventional	59.4 b	54.1 b	51.7 ns	102.9 ns	2.1 ns	5.1 b
Physical	72.1 a	61.9 a	52.1 ns	126.1 ns	21.9 ns	56.0 a

Weed control and yield

During 2006, before crop-transplanting, the weed community was made up of *Solanum nigrum* L. (70%), *Convolvulus arvensis* L. (8%), grass species (6%) and other weeds (16%). As the cropping cycle proceeded, *Portulaca oleracea* L. became the major weed with a relative density varying from 30 to 40%. Low and constant weed densities were observed in the conventional system (1–10 plants m^{-2}; Table 4). Weed density fluctuated more and tended to be higher for the physical system, ranging from 16 to 68 plants m^{-2}, even though it appeared that complete weed control was achieved immediately after broadcasted physical treatments (rolling harrowing and flaming before crop transplanting).

Rolling harrowing (before crop transplanting), flaming (before crop transplanting) and the first precision hoeing appeared to control the weeds completely, immediately after treatments were applied in 2006. The effectiveness of the second hoeing was about 50%, probably because of the presence of more developed weeds in the row which had not been removed by manual weeding. Vigorous development of the crop made weeding more difficult and consequently lowered the effectiveness of weeding. Weed biomass at the end of the cropping cycle was similar for both farming systems and averaged between 103 and 126 g m^{-2} (Table 5).

In 2007, initial weed composition consisted primarily of various grass weeds (50%) and *Chenopodium album* L. (over 30%). Later on, the main components were *Cynodon dactylon* (L.) Pers. (50%), *Chenopodium album* L. (13%), *Cyperus* spp. (10%) and *Amaranthus retroflexus* L. (10%). The conventional system showed a constant and low density (on average between 2 and 5 plants m^{-2}), while weed density varied from 2 to 35 plants m^{-2} for the physical system (Table 4). The stale seedbed technique achieved 100% weed control immediately after the flaming treatment, while weed control varied from 70 to 90% right after plots were hoed. Differences in weed dry biomass at harvest were not detected between the physical system and the conventional system in 2007 (Table 5).

Weed composition was similar in 2008 to that in 2006. Initial weed density was about 300 plants m^{-2}. The rolling harrow appeared to achieve 100% weed control immediately after being used. Before flaming, weed density was about 20 plants m^{-2}, and complete control of emerged weeds resulted after imposing the flaming treatment. Weed density before the first and the second post-transplanting pass with the precision hoe was about 80 and 50 plants m^{-2}, respectively. Hoeing effectiveness was similar to 2006 and 2007. Weed density averaged between 2 and 14 plants m^{-2} in the conventional system and between 17 and 77 plants m^{-2} in the physical system (Table 4). Weed dry biomass at harvest was significantly lower for the conventional system than the physical system (5 versus 56 g m^{-2}, Table 5).

The conventional system was generally more effective in controlling weed density than the physical system (Table 4). However, weed biomass differences between the two systems were detected only in 2008 (Table 5), and these differences did not result in a lower tomato yield in the alternative system. In fact, fresh tomato yield in 2006 and 2007 for the physical system was 14–21% greater than in the conventional system. This increase in crop yield for the physical system could be due to benefits in root system growth resulting from soil crust breaking, soil aeration and soil water capillary rise interruption[24,25] provided by the tillage performed in the physical system. Precision hoeing enabled soil between the paired rows to be tilled, which was not possible with the conventional system using a PTO-powered rotary hoe.

The lack of consistency in rank of the two control systems across the 3 years confirms that it is not possible to identify the best strategy in absolute terms, since efficacy was dependent on the environmental conditions present when the various control methods were applied. However, this study indicates that physical weed control can be an effective alternative to herbicides in some environments. In some instances, crop yield can be elevated when physical control methods are used rather than chemical methods.

Conclusions

Results of this study indicate that the equipment can be modified for physical weed control in tomato, even when planted in paired rows, where physical weed control can be problematic. The physical strategy required a higher labor input than the conventional strategy. Weed density tended to be lower in the conventional control system which included herbicide applications, but weed density was lowered and suppressed using the physical control strategy. Physical management enabled the weed presence to be reduced and contained without affecting crop yield. In fact tomato yield was never lower and was sometimes greater

using the physical control strategy, possibly because of precision hoeing methods that allowed soil within the paired rows to be tilled. This study confirms that the efficacy of weed control methods is closely linked to environmental factors. Nevertheless, physical control methods seem to be an effective alternative to herbicides for weed control in tomato. Good weed control and high crop yield can occur when physical weed control methods are used in tomato production. An advantage of relying on physical weed control methods is that a premium might be paid for the tomato crop that is grown.

Alternative strategies for weed control are very important for European farmers, as the new regulations will lead to a significant reduction in the active ingredients allowed, including herbicides. Pesticide applications in Europe are ruled by an EU directive on the promotion of sustainable and reduced risks for crop protection plans. The EU's general principles of integrated pest management encourage the use of non-chemical, mechanical and physical methods.

Weed control is always a key problem in agriculture; thus, there is a clear need for further research in this field. Over the past two decades, agricultural land has been increasingly managed according to the availability of new technologies, including global positioning systems, geographic information systems, sensors, the automation of agricultural machinery and high-resolution image sensing. In fact, non-chemical weed control could be enhanced by implementing specific machines with automatic and robotic systems for the mechanical and thermal management of spontaneous flora. There is now a variety of equipment dedicated to specific crops and agricultural environments. Row detection systems represent the first level of implementable technology for all precision hoeing machines. A camera, connected to a specific electronic device, can recognize crop rows and move the precision hoe in accordance. This saves labor times as the back-seated operator is no longer required. Intelligent weeders are equipped with software that can move specific tools in and out of the crop row and/or around the crop.

The machines and strategies presented in this work are low-tech machines but at the same time are cheap and effective. Providing low-tech machines with electronic devices for physical weed control may be possible in the near future and would be a good way to save on labor. The cost of producing a dedicated machine would be much higher. In this sense, the machines built and tested at the University of Pisa are versatile, as they can be reliably used without electronic devices (i.e., for family-run farms, small farms, developing countries, etc.) but are still implementable with hi-technologies (i.e., for large farms, hi-value crops, etc.).

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Barriers to the adoption of management-intensive grazing among dairy farmers in the Northeastern United States

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Abstract

This paper uses recent survey results from almost 1000 dairy producers in northeastern US to analyze farmers' perceptions of barriers to the adoption of rotational grazing [management-intensive grazing (MIG)] as a means for feeding their dairy herds. The survey found that approximately 13% of dairy producers in the region were using MIG during the 2006 growing season. Approximately 40% of farmers surveyed were using a confinement feeding operation where the milking herd does not graze at all and close to 47% were using a traditional system that involved some pasture forage for the milking herd. Regardless of the popular sentiment that increased information and technical assistance is needed in the field, producers more frequently report a series of other barriers as being greater obstacles to the adoption of MIG. Farmers using confinement feeding tended to see each of the barriers presented as being more significant obstacles than did other farmers. Farmers with higher debt ratios and higher milk production per cow were more likely to view the financially related barriers (decreased milk production per cow, cash flow and farm profits) as significant obstacles.

Key words: dairy farming, management-intensive grazing, rotational grazing, technology adoption, barriers to adoption

Introduction and Background

When confronted with how to best deal with growth and farm viability issues, dairy and livestock producers in northeastern US often find themselves at a fork in the road of their future. One path leads toward the creation of much larger herd sizes supported by confinement feeding systems that require large amounts of capital to establish and operate. Another well-traveled path leads many producers to exit the industry. The total number of dairy farms in the region (which includes New York, Vermont, Pennsylvania, Maryland, New Hampshire, Massachusetts, Rhode Island, Connecticut and Maine) has decreased by more than 81% since 1960 (Fig. 1). This describes the 'get big or get out' pressure that is well known to producers. A third, and lesser-used, path for dairy and livestock producers follows an often smaller-scale, lower-cost alternative based on the use of management-intensive grazing (MIG). Each of these paths results in very different outcomes with implications for the farm sector, rural communities, food systems and the environment. A plethora of information sources, some peer-reviewed science and others anecdotal, indicate that the expanded adoption of MIG may have very positive effects on the aforementioned sectors. Hence, the expanded adoption of MIG and the associated barriers are the focus of this paper.

There are several reasons that the adoption of MIG has received the attention of many agricultural researchers and USDA field and state office staff. The use of MIG has the potential to improve farm financial viability relative to other dairy production systems, despite lower milk production per cow[1–4]. A reduction in variable and fixed production costs is the cause of these results.

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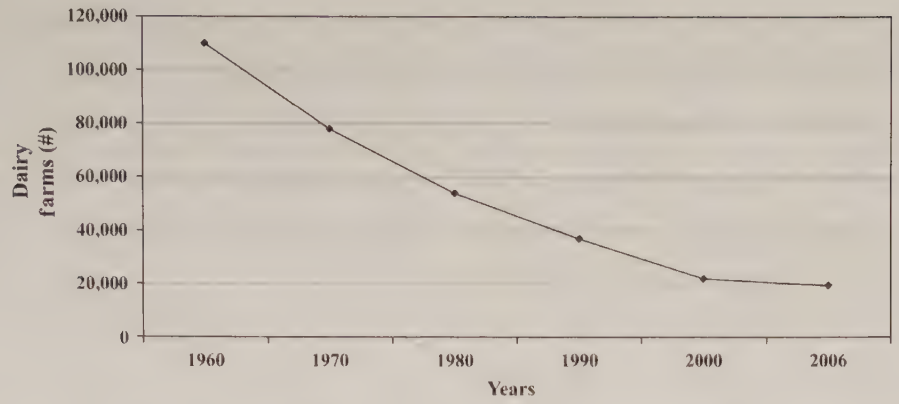

Figure 1. Total number of dairy farms in the Northeast, 1960–2006. Source: USDA National Agriculture Statistics Service, *Quick Stats, U.S. and State Data, Dairy.*

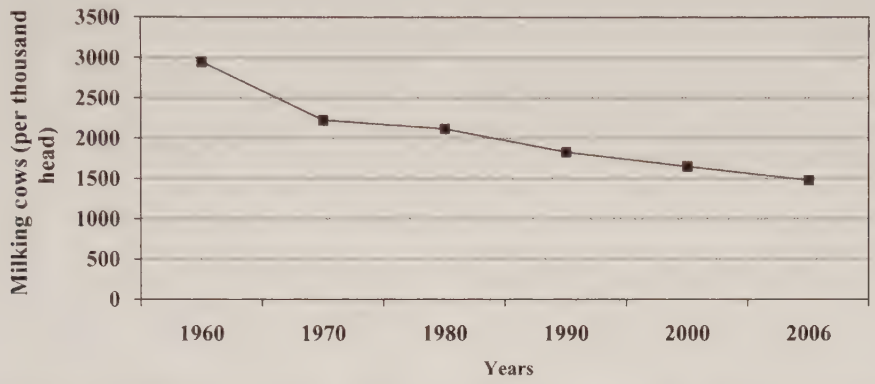

Figure 2. Total number of milking cows in the Northeast, 1960–2006. Source: USDA National Agriculture Statistics Service, *Milk Cows and Production.*

The environmental benefits of MIG accrue primarily from having permanent vegetative cover on agricultural soils and requiring much lower applications (often none) of pesticides or chemical fertilizers. The use of MIG has been shown to reduce losses of nutrients and sediments from agricultural land, thereby reducing the negative impact of dairy production on water quality issues[5–9]. The use of MIG has also been shown to reduce net greenhouse gas emissions per acre from dairy production, by using less fossil fuel and sequestering carbon in the soil[10]. Regarding wildlife habitat, researchers in Wisconsin have found that the use of MIG, relative to current agricultural land use, is advantageous for ground-dwelling birds[5,11]. While MIG's impact on herd health, the food system, farm family quality of life and rural communities is not yet thoroughly documented in the scientific literature, the popular press indicates potential benefits in these areas[12–17].

The Northeast Dairy Farming Sector

In the northeastern region, where dairy production has been the dominant source of agricultural revenues for almost 100 years, there has been a dramatic decline of 81% in the number of dairy farms since 1960 (Fig. 1). The current national trend is consolidation into fewer but larger farms and the result of this trend can be observed in the Northeast. The number of milking cows in the region has decreased by 49% from approximately 2,948,000 in 1960 to 1,480,100 in 2006 (Fig. 2). While the number of milking cows and dairy farms has steadily declined across the region, the average number of milking cows per farm has increased by nearly 50% indicating consolidation into fewer, larger farms[18]. Additionally, milk production per cow has nearly doubled over this period[19].

Survey and Methods

Surveys were mailed to over 4000 dairy farmers in four northeastern states (Vermont, New York, Pennsylvania and Maryland) during spring 2007. These four states were selected, because they represent various climatic and soil conditions present within the region and because this study did not have the resources to survey farmers in all states. The mail survey was administered following the Dillman method[20]. Due to the small number of dairy farms in both Vermont and Maryland, all dairy farms in those states were included in the sample. For New York and Pennsylvania, states with sizeable dairy farm populations, dairy farms were selected at random to be included in the sample. The mailing lists of dairy farms in Vermont were provided by

29. Regardless of your interest in using rotational grazing, please indicate how great of a challenge each of the following would be for adopting rotational grazing on your farm.
(1=not a challenge to 5=significant challenge)

	Not a challenge		Neutral		Significant challenge
Decrease in milk production per cow	1	2	3	4	5
Decrease in cash flow	1	2	3	4	5
Decrease in farm profits	1	2	3	4	5
Lack of information on pasture management	1	2	3	4	5
Lack of on-farm technical assistance	1	2	3	4	5
Amount of work to start rotational grazing	1	2	3	4	5
Amount of work to manage rotational grazing	1	2	3	4	5
Skepticism from other farmers	1	2	3	4	5
Skepticism from family members	1	2	3	4	5
Difficulty producing enough winter feed	1	2	3	4	5
Not enough land for grazing	1	2	3	4	5
Other physical farm constraint	1	2	3	4	5
Other challenge	1	2	3	4	5

Figure 3. The Northeast Dairy Farm Practices Survey question for farmers not grazing in 2006.

the Department of Community Development and Applied Economics at the University of Vermont; for Pennsylvania, by the Bureau of Animal Health and Diagnostic Services for the Pennsylvania Department of Agriculture; for New York, by the New York State Department of Agriculture and Markets and for Maryland, by the Division of Milk Control in the state Department of Health and Mental Hygiene.

The initial mailing took place in March 2007. A reminder postcard followed 3 weeks later. Farms that did not respond to the initial mailing were sent a second survey in April 2007, 6 weeks after the original mailing. The number of usable surveys returned was 987. This includes 365 from Vermont, 252 from New York, 237 from Pennsylvania and 133 from Maryland. This resulted in a response rate of 24.5%. The length of the survey (six pages of questions) and the proximity of the survey to the beginning of the spring cropping season may have hampered the response rate.

The respondents were asked to answer the questions for their farm as it was during the year 2006. The survey included questions on herd size, milk production, land use, farmer characteristics, technologies and management practices, satisfaction levels with aspects of the operation, concerns for long-term survival of the farm, plans for the future of their farm, as well as feeding and grazing practices. A series of questions in the survey asked dairy farmers to indicate how great of a challenge each of the 11 factors (plus two 'other' categories) would be for adopting MIG on their farm. The structure of the survey guided respondents to separate sections based on whether or not they were using grazing for their milking herd in 2006. The questions from the survey, as they were posed to non-graziers, are reproduced and shown in Figure 3.

This information was solicited from all respondents, albeit in different ways. Farmers that were grazing their milking herd in 2006 answered the questions shown in Fig. 3 in two parts. The first part asked, 'Prior to adopting

grazing, what did you expect the challenges would be?' The second part asked, 'What did you find the challenges to grazing actually were?' This provided some insight into the difference between perceived and actual challenges to the adoption of MIG from those who underwent the transition on their farms. Farmers who were not using pasture as a source of forage for their milking herd in 2006 were asked about the challenges they *perceived* regarding the adoption of grazing.

The analysis presented in this paper is based on the survey results. Each farm has been categorized into one of the three groups reflecting three distinct types of dairy production systems common in the Northeast and relevant to this analysis. These include farms using MIG ($N = 134$), confinement feeding (CONF) ($N = 396$) and traditional (TRAD) ($N = 459$) systems. On farms using MIG, the milking herd gets a fresh paddock every 12 or 24 h and cows receive the majority of their forage intake from pasture when adequate pasture forage is available. On farms using CONF, the milking herd does not graze at all. On farms using TRAD systems, the milking herd does graze, but in a less intensive manner than MIG. Respondents who did not answer the questions necessary for being categorized into a production system ($N = 37$) were deleted from the sample.

The results presented in this paper were developed with one of several basic statistical analyses most appropriate for the specific questions being asked. The Chi-square test (χ^2) was used to determine if significant relationships exist among a set of categorical variables, particularly whether farm and farmer characteristics differed according to the type of production system used. The Kruskal–Wallis test, a non-parametric analysis of variance, was used to determine differences in the way farmers using the three production systems viewed the barriers to the adoption of grazing. The non-parametric Wilcoxon Signed Rank test (Z) was used to determine if significant differences exist in farmers' perceptions of the barriers to adoption of rotational grazing before versus after adoption. The non-parametric Spearman correlation analysis was used to determine if certain factors such as milk production per cow and debt level determine how farmers view the barriers to adoption of rotational grazing. Logistic regression analyses were used to determine the influence of farm and farmer characteristics, including production system used, on farmers' perceptions of each of the 11 barriers analyzed.

Results and Discussion

The statistical analyses reported in this paper were performed using the SPSS statistical software (SPSS Inc., Chicago, Illinois, USA). An alpha level of 0.05 was the criterion for statistical significance for all tests. All results discussed in this paper were found to be statistically significant. The sections below expand upon the survey results, including farmers' perceptions of the implementation and use of MIG on their farms.

Table 1. Mean (and median) herd size, acres and milk per cow by production system.

	Herd size	Acres	Milk production per cow (lbs/year)
MIG	65 (55)	231 (179)	14,886 (15,045)
TRAD	69 (60)	232 (192)	16,656 (17,000)
CONF	193 (111)	493 (320)	20,460 (20,801)

General survey results

CONF farms tended to have larger milking herds and farmed more acres than either TRAD or MIG farms (Table 1). CONF farms also had higher milk production per cow than the other farms. This may be due to the reduced energy expended by cows in confinement, the ability of producers to precisely balance supplemental nutrients in the feed ration relative to farms using pasture forage, and producer goals and preferences.

Differences in farmer characteristics were also noted among these three production systems (Table 2). Farmers using MIG were more likely to have completed a bachelor's degree or beyond. Farmers using CONF (followed by TRAD and MIG) were more likely to list their primary source of farm management information as their veterinarian (25, 18 and 18%), feed sales representative (19, 15 and 11%) and consultants (17, 9 and 6%). They were less likely to seek information from their state extension service (6, 8 and 11%), other farmers (8, 17 and 15%), or publications (17, 25 and 24%). Although still not one of the top sources of information, it is interesting to note that a higher percentage of farmers using MIG received information from their University Extension System (11%).

A vast majority of CONF farms used a total mixed ration compared to TRAD and MIG farms (Table 3). CONF farms were also using recombinant bovine somatotropin (rBST) more than TRAD and MIG farms. They were also more likely to have a milking parlor, a manure storage lagoon, a written nutrient management plan and hire custom manure spreading services. A greater percentage of confinement feeding farms (27%) report having high or very high debt levels (defined as having debt that is >40% of total farm assets), relative to TRAD (16%) or MIG farms (15%).

Nearly 25% of the farms using MIG were selling certified organic milk in 2006. MIG farms were also much more likely to be in the transition to organic certification, or considering it (26%), compared to TRAD (15%) and CONF (3%). These findings make sense given that the standards for organic certification require at least a minimum level of pasture forage intake. A much greater percentage of MIG farms (42%) had a seasonal calving pattern in their herd compared to TRAD (21%) or CONF (7%). The MIG farms with seasonal calving patterns tended to have spring calving herds (52%) and the primary reason given for this was to maximize pasture forage intake (87%).

As a group, farmers using MIG reported higher mean satisfaction scores across various aspects of their farming

Table 2. Characteristics of the farm's primary decision maker by the production system.

	Mean age	Male (%)	Female (%)	Some H.S. (%)	Highest level of education: H.S. or equivalent (%)	College or vocational training (%)	Completed bachelor's degree (%)	Master's degree or higher (%)
MIG	50	86	12	9	42	18	27	4
TRAD	51	90	9	17	45	24	12	2
CONF	52	92	7	17	39	24	19	1

Table 3. Use of technologies and management practices for which significant ($P < 0.05$) differences exist across farm types.

	MIG		TRAD		CONF		Total	
	N	%	*N*	%	*N*	%	*N*	%
Milking parlor	42	32.3	123	28.6	219	56.7	384	40.6
Tie stall/stanchion with pipeline	77	63.1	289	68.8	157	48.3	523	60.3
Other milking system	13	16.5	53	19.6	25	11.7	91	16.1
Automatic takeoffs	25	20.3	110	26.4	219	57.9	354	38.6
Written nutrient plan	57	45.2	182	42.3	243	63.8	482	51.4
Manure storage pit	63	48.8	222	50.0	288	74.4	573	59.7
Custom manure hauling	31	24.6	83	19.4	145	38.9	259	28.0
Total mixed ration (TMR)	24	19.2	172	39.4	322	82.8	518	54.5
Dairy herd information association (DHIA)	78	60.0	235	53.7	262	69.1	575	60.7
Recombinant bovine somatotropin (rBST)	6	4.7	30	7.0	101	27.4	137	14.8
Computer for farm management	46	35.9	111	25.8	186	49.9	343	36.8
Farm financial consultant	24	19.0	79	18.6	148	40.2	251	27.3
Crop/nutrient management consultant	55	43.3	193	45.0	256	67.9	504	54.0

Table 4. Farmer satisfaction and concerns for future. Percent of survey respondents satisfied or very satisfied (where 1 = very dissatisfied, 4 = satisfied and 5 = very satisfied) and somewhat or significantly concerned (where 1 = not a concern, 4 = a concern and 5 = a significant concern) with various aspects of their farming operation by the production system.

	MIG	TRAD	CONF
Satisfaction			
Overall mean satisfaction	3.11	2.88	2.93
Farm profit	18.9%	12.0%	11.7%
Financial progress	34.1%	21.2%	24.8%
Herd health	76.0%	62.6%	55.3%
Anxiety/stress level	26.3%	16.3%	17.1%
Impact of farm practices on water quality	70.5%	59.6%	59%
Concerns for future			
Milk price	79.0%	89.6%	93.1%
Herd size not viable in 5 years	12.2%	19.8%	21.5%
Likely or *very likely* to go out of business in the next 5 years	12.1%	18.8%	17.1%

*Statistically significant differences ($P < 0.05$) exist among production systems for each item.

operation, with an overall satisfaction score of 3.11 (where 1 = *very dissatisfied* and 5 = *very satisfied*) (Table 4). Farmers using TRAD and CONF systems reported the overall mean satisfaction scores of 2.88 and 2.93, respectively. A higher percentage of MIG farmers, relative to TRAD or CONF farmers, reported being *satisfied* or *very satisfied* with their farm's profit level (18.9, 12.0 and 11.7%), financial progress over the past 5 years (34.1, 21.2 and 24.8%), herd health (76.0, 62.6 and 55.3%), anxiety and stress levels (26.3, 16.3 and 17.1%) and impact of farm on water quality (70.5, 59.6 and 59.0%). Although it is a concern for the vast majority of farmers, a smaller percentage of farmers using MIG reported *moderate* or *significant concern* for the future of their farm regarding farm-gate milk prices (79.0, 89.6 and 93.1%). A smaller percentage of farmers using MIG reported *moderate* or *significant concern* about the viability of their current herd size over the next 5 years (12.2, 19.8 and 21.5%) and with less frequency reported *likely* or *very likely* to exit the dairy industry during the next 5 years (12.1, 18.8 and 17.1%). In summary, the survey data paint a picture of farmers who are using MIG considering their farms to be in a stronger position for the future with greater frequency, relative to farmers using TRAD or CONF systems.

Barriers to adoption of MIG

Figure 4 shows the frequency with which farmers in each of the three production systems indicated that each of 11 factors was a *moderate* or *significant challenge* for the

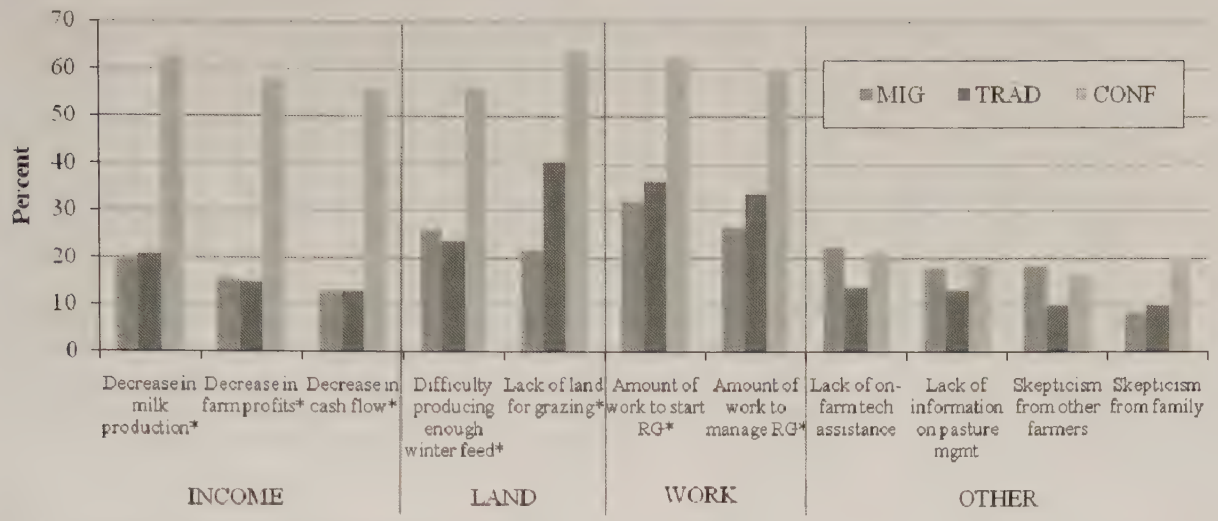

Figure 4. Percentage of farmers indicating that each factor is a *moderate or significant challenge* to the adoption of MIG on their farm, by production system. RG, Rotational grazing. *Indicates statistically significant difference of $P < 0.05$.

adoption of MIG on their farm. As shown, the factors related to income, land and labor were more frequently seen as barriers for farmers of CONF production systems than were factors related to information, technical assistance or skepticism from other farmers or family. In the field, the authors often hear the need for more technical assistance discussed as the prominent issue hindering the expanded adoption of MIG. What these results indicate is that while information and technical assistance to farmers are probably necessary for expanded adoption of MIG, supplying these items alone may not be sufficient. This section discusses the results of in-depth analysis related to the barriers to adoption.

Farmers using CONF view many of the barriers as a more significant obstacle, with greater frequency, relative to farmers using MIG or TRAD systems (Fig. 4). The barriers for which this was most often the case were those related to farm financial performance. These include the barriers *decrease in milk production*, *decrease in cash flow* and *decrease in farm profits*. This is probably due to a combination of real and perceived outcomes. As discussed above, cows in MIG systems (and to a lesser extent TRAD) systems generally produce less milk than cows in CONF systems; hence, lower milk production is a real concern for farmers of CONF operations. Lower milk production per cow can translate into reduced cash flow if expenses are not reduced by an equal or greater percentage. However, numerous studies have shown that profit per cow and per unit milk production is often higher on farms using MIG[1–4,17,21]. It seems that the assumption that lower milk production per cow leads to reduced cash flow and farm profits seems to be prevalent among farmers using CONF production systems.

While CONF farmers' consistently perceived financial, labor and land issues as greater barriers than did MIG or TRAD farmers, a few significant differences existed between MIG and TRAD farmers with regard to how they perceived barriers to adoption. The Kruskal–Wallis test revealed that the only statistically significant difference between MIG and TRAD farmers related to the barrier *lack of land for grazing* ($\chi^2 = 46.446$, $P = 0.001$). Farmers using MIG systems saw this as a barrier less frequently than did farmers using TRAD systems. This result may have two causes. First, given that the stocking rate, measured as milking cows per acre of crop and pasture land, on MIG farms (0.52) was not statistically different from that on TRAD farms (0.47) (Table 1), this suggests that MIG farms are making more productive use of their pastures. Second, this result may also be due to the unwillingness of farmers in the TRAD group to use tillable cropland for pasture, as is done on many MIG farms.

The Wilcoxon Signed Rank Test revealed that, for farmers using MIG, many of the barriers to adoption that they expected to encounter *prior* to adopting MIG were actually less of a challenge than they had anticipated *after* adoption (Fig. 5). This includes the variables *decrease in milk production* ($Z = -1.980$, $P = 0.048$), *decrease in cash flow* ($Z = -3.056$, $P = 0.002$) and *decrease in farm profits* ($Z = -3.427$, $P = 0.001$), as well as skepticism from family members ($Z = -2.675$, $P = 0.007$). Because the perceived barriers for MIG and TRAD farmers were roughly equivalent and the actual barriers encountered by MIG farmers after adoption were far less than expected, these results can be extrapolated to imply that the actual barriers to adoption for TRAD farmers should also be less than perceived barriers.

It was hypothesized that positive relationships exist between how farmers view the significance of certain barriers to adoption of MIG and the farm's level of debt and milk production per cow. A Spearman correlation analysis of this dataset revealed that this was the case for some of the barriers. For example, farmers with a greater debt-to-asset ratio are more likely to view the variable *decrease in cash flow* as a significant barrier to the adoption of

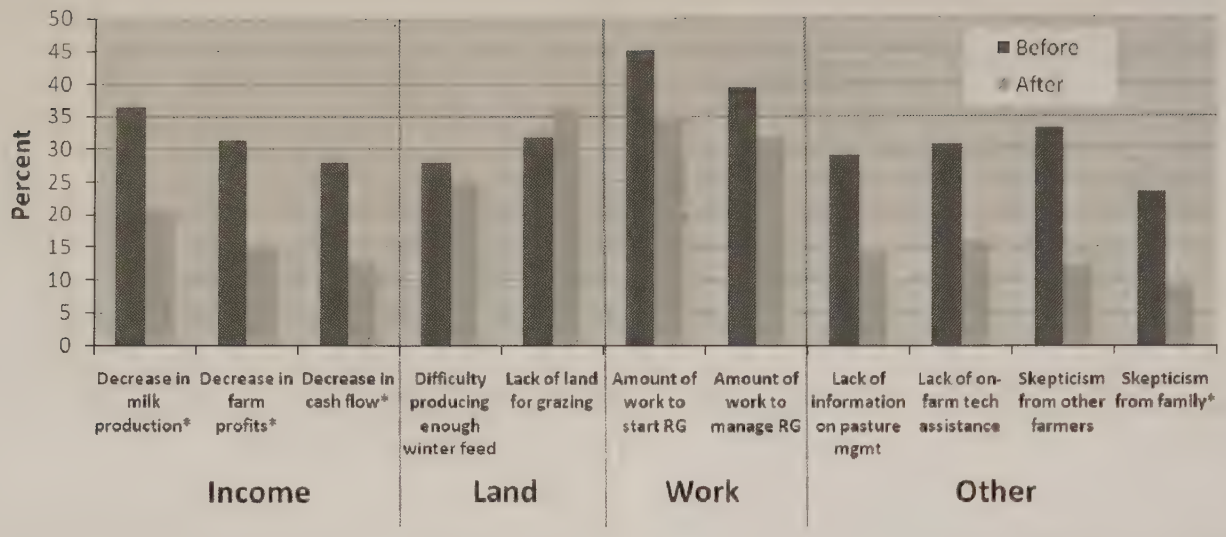

Figure 5. Perceived barriers (i.e. before adoption) and actual barriers (i.e. after adoption) to the adoption of MIG for farmers using rotational grazing. RG, Rotational grazing. *Indicates statistically significant difference of $P < 0.05$.

MIG [r (461) = 0.125, $P = 0.007$]. The reason for this result may be that farms with higher debt per cow may feel the need to maximize milk production per cow in order to keep up with monthly debt service payments. Farmers may view any change that results in lower milk production per cow as a threat to cash flow and, by extension, farm profits.

For respondents with greater milk production per cow, often farmers using CONF systems, the correlation analysis revealed that there is a strong relationship between milk production and perceived barriers. The barriers of *decrease in milk production* [r (344) = 0.276, $P = 0.001$], *decrease in cash flow* [r (342) = 0.175, $P = 0.001$] and *decrease in farm profits* [r (343) = 0.204, $P = 0.001$] were widely viewed as greater obstacles by CONF farmers with higher milk production per cow. This result was not observed for farmers using MIG. This, in combination with many studies that show MIG to be as, or more, profitable than other production systems[1–4], may help accentuate the important point that higher milk production per cow does not necessarily translate into higher farm profits.

Determinants of real and perceived barriers to adoption

Regression analyses were performed to determine which factors had the greatest influence on farmers' perceptions of each of the 11 barriers presented. For this analysis, 11 individual logistic regressions were run, one for each barrier presented in the survey. The logistic regression method of analysis was chosen for two important reasons. First, the current analysis is most interested in identifying whether or not each factor was perceived as a challenge. Second, the logistic regression method simplified the interpretation of the resulting coefficients in each model. For this analysis, the five ordinal categories of the dependent variables were recoded as binary categories. *Not a challenge* (1), *minimal challenge* (2) and *neutral* (3) categories were condensed and recoded as *not a challenge* (0). *Somewhat significant challenge* (4) and *significant challenge* (5) were condensed and recoded as *challenge* (1). The explanatory (right-hand side) variables used to explore and explain the impact of each barrier were the same across all regression models. These variables included the state the farm was located in, herd size, milk production per cow (per 10,000 lbs), stocking density (cows per acre), an index of farmer satisfaction with their farming operation, farmer age, farm debt level (as a percentage of total farm assets) and the production system employed (CONF, MIG or TRAD).

Seven of the 11 regression models were significant. These included the models explaining *decrease in milk production*, *decrease in farm profits*, *decrease in cash flow*, *lack of on-farm technical assistance*, *skepticism from other farmers*, *difficulty producing winter feed* and *not enough land for grazing* (Table 5). However, the significant explanatory variables differed across the models (Table 6).

Regarding the barriers related to farm income and profitability, only a handful of factors were statistically significant at the 95% confidence level. For the barrier *decrease in milk production*, farmers in New York and Vermont saw this as less of a barrier than did farmers in Pennsylvania or Maryland. As expected, farmers with higher milk production per cow perceived this barrier to be more significant than did farmers with lower milk production per cow. For the barrier *decrease in cash flow*, the only significant variable was herd size. This implies that farmers with larger herd sizes saw the impact of adopting MIG on cash flow to be a greater challenge than did farmers with smaller herd sizes. Although decreased milk production per cow is a likely outcome of adopting MIG, the impact on cash flow and farm profitability could be either positive or negative. Decreased cash flow and profitability were included as barriers in the survey because many farmers identify these as barriers to the adoption of MIG.

Table 5. Summary results from logistic regression models to determine which factors had the greatest influence on each of the 11 barriers to the adoption of rotational grazing (RG).

	Model summary			
Challenge variable	**Chi-square**	***P*-value**	**−2 log likelihood**	**Nagelkerke R^2**
Decrease in milk production	68.309	0.001	482.537	0.208
Decrease in farm profits	50.470	0.001	510.562	0.156
Decrease in cash flow	54.424	0.001	506.992	0.167
Difficulty producing enough winter feed	39.844	0.001	515.858	0.126
Lack of land for grazing	68.878	0.001	479.269	0.211
Amount of work to start RG	14.286	0.218	531.816	0.047
Amount of work to manage RG	13.144	0.284	539.341	0.043
Lack of on-farm technical assistance	22.992	0.018	401.051	0.085
Lack of information on pasture management	19.382	0.055	384.599	0.074
Skepticism from other farmers	24.825	0.010	388.975	0.093
Skepticism from family members	13.856	0.241	399.465	0.053

Table 6. Logistic regression results for statistically significant models.

	Explanatory variables											
	State (ref = MD)											
Model	**NY**	**VT**	**PA**	**Herd size**	**Milk prod.**	**Stocking density**	**Satisfaction index**	**Age**	**Debt 0–1**	**CONF 0–1**	**TRAD 0–1**	**Constant**
Decrease in milk production												
P-value	0.036*	0.001	0.074	0.062	0.001	0.813	0.909	0.361	0.248	0.533	0.104	0.094
Exp (B)	0.450	0.246	0.491	1.002	2.846	1.070	1.021	1.009	1.370	1.322	0.444	0.178
Decrease in farm profits												
P-value	0.121	0.032	0.370	0.008	0.016	0.232	0.997	0.286	0.348	0.887	0.032	0.147
Exp (B)	0.582	0.480	0.724	1.002	2.001	0.740	0.999	1.010	1.274	0.940	0.346	0.242
Decrease in cash flow												
P-value	0.223	0.060	0.957	0.006	0.438	0.422	0.785	0.212	0.434	0.249	0.079	0.207
Exp (B)	0.653	0.526	0.981	1.002	1.250	1.261	0.954	1.012	1.225	1.658	0.412	0.287
Difficulty producing enough winter feed												
P-value	0.291	0.236	0.115	0.945	0.517	0.987	0.325	0.355	0.978	0.052	0.290	0.728
Exp (B)	0.697	1.478	1.748	1.000	0.830	1.003	0.847	1.009	1.007	2.395	0.586	0.715
Lack of land for grazing												
P-value	0.329	0.692	0.129	0.371	0.400	0.001	0.237	0.017	0.531	0.003	0.391	0.011
Exp (B)	0.702	1.152	0.569	1.001	1.284	7.418	0.808	1.025	1.187	4.374	1.593	0.061
Lack of on-farm technical assistance												
P-value	0.169	0.021	0.647	0.482	0.494	0.118	0.423	0.309	0.916	0.078	0.159	0.417
Exp (B)	0.587	0.407	1.191	0.999	0.802	1.553	1.174	1.011	0.968	0.442	0.490	0.402
Skepticism from other farmers												
P-value	0.078	0.004	0.034	0.826	0.732	0.742	0.771	0.761	0.743	0.002	0.134	0.711
Exp (B)	0.522	0.338	0.431	1.000	1.118	0.902	1.062	0.997	1.107	0.232	0.478	1.531

For the barrier *decrease in farm profits*, the significant variables were herd size and milk production per cow. Farmers in Vermont and farmers using TRAD systems saw a *decrease in farm profits* as less of a barrier.

None of the variables in the model for the barrier *difficulty producing enough winter feed* were significant. However, for the barrier *not enough land for grazing* there were several significant variables. As expected, farms with higher stocking densities were more likely to recognize *not enough land for grazing* as a barrier to the adoption of MIG. Additionally, older farmers and farmers using CONF systems saw this as a greater barrier.

The only significant variable in the model analyzing the barrier *lack of on-farm technical assistance* was that farmers in Vermont saw this as less of a barrier than did farmers in the other three states. This is likely to be a result

of the past and current work from a small, dedicated group of faculty and staff at the University of Vermont. Dr Bill Murphy and his staff provided information and on-farm technical assistance to scores of farmers during the 1980s and 1990s. This work is currently carried forward by UVM's Center for Sustainable Agriculture.

Farmers in Vermont and Pennsylvania viewed *skepticism from other farmers* as less of a barrier to the adoption of MIG than did farmers in New York or Maryland. Farmers using CONF also viewed *skepticism from other farmers* as less of a challenge than did other farmers (Table 5).

Summary and Conclusions

MIG systems, if more widely adopted in the Northeast, have the potential to provide many public and private benefits. Understandably, farmers are hesitant to make radical changes to their existing management systems because change can be a source of risk. For this reason, publicly supported programs may be necessary to assist farmers who want to evaluate and consider adopting MIG, just as support programs are available to other types of farming operations.

Although only a small percentage of dairy farmers in the Northeast currently practice MIG, significant increases in the adoption of MIG could be quickly realized with the creation of incentive programs that help farmers overcome barriers to adoption. It is essential that such programs be appropriately designed to address the most significant barriers (both real and perceived) that farmers face. Although additional information and technical assistance for farmers are essential for an expanded adoption of MIG, the results presented in this paper show that programs to help farmers overcome the barriers related to income, land and labor are also essential to achieve wider adoption.

If our society deems it worthy to encourage a larger percentage of farmers to consider adopting MIG, there are numerous policy options that could be explored that would address the income, land and labor barriers. These options include, but are not limited to, the following ideas:

- The creation of programs to restructure farm debt would allow farmers with high debt per cow to consider transitioning to MIG. Farms with high debt per cow often feel that it is essential to have maximum milk production per cow. Because MIG often results in lower per cow milk production, many farmers feel that MIG is not a viable option for their farm.
- Debt-for-carbon swaps, where farmers provide quantifiable carbon sequestration credits from the use of MIG in exchange for debt reduction. Additional types of 'green payments' programs can be considered based on water quality and other environmental quality improvements resulting from the use of MIG.
- Revenue assurance during the transition to MIG, based on documented farm financial performance over recent years. This would provide farmers with a guarantee that their net farm income will not decrease during the transition period to MIG and would greatly reduce the perceived risks associated with this transition.
- Visas for persons with demonstrated skills and experience with MIG to work legally in the US Skilled graziers from countries like New Zealand, Ireland, Argentina and South Africa would help their US employers make the transition to MIG and help to alleviate the labor constraints associated with this transition.

In addition to their direct impact, the programs listed above would also signal to the farming community that MIG is a viable production system and one that society deems desirable. The results presented in this paper may be used to provide this important information to policy-makers.

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Incorporating native plants into multifunctional prairie pastures for organic cow–calf operations

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Abstract

The multifunctional agronomic, ecological, economic and social uses of grass-based agricultural systems in peri-urban Marion County, Iowa, were the subject of investigation from 2003 to 2005. Following a sociocultural analysis that identified diverse motivations of cow–calf operators, an on-farm, agroecological experiment was established with a member of the study group. The objective of the experiment was to investigate the feasibility of establishing a multifunctional prairie pasture in response to the operator's interest in certified organic, warm-season plant species paddocks. At the field level, the implementation of native grasses and legumes into fallow pasture without the use of herbicides under flash grazing, mowing and unmanaged control treatments showed differences in species establishment and pasture composition. After three growing seasons, native species were evident in all treatments, with no significant differences between grazing and mowing in total native species establishment. There was a trend toward greater native legume establishment in the control over the managed treatments. Thus, total species abundance was greatest in control plots, suggesting this treatment for maximum prairie pasture establishment without herbicides. Concurrence was observed between motivations expressed by cow–calf operators in the sociocultural study (i.e. biodiversity preservation and sustainable management of natural resources) and outcomes from the prairie pasture experimental system. Support for grass-based systems from local institutions at the community level is necessary for the expansion of prairie pastures in Iowa and throughout the tallgrass prairie region.

Key words: organic, agroecology, burning, tilling, mowing, grazing, competition, native species, plant interactions

Introduction

Prairie as pasture

In proportions similar to those recorded across the US Corn Belt, pasturelands occupied approximately 10% of Iowa's surface area in 2002, and 14% of south central Marion County, Iowa[1], the location of this study from 2003 to 2005. Iowa lies within the natural boundaries of the tallgrass prairie region, a bounteous zone supporting more than 450 species of plants through climatic, fire and grazing cycles[2]. The pattern adopted by early settlers of replacing native, perennial warm-season grasses, legumes and forbs with introduced plant species, such as tall fescue (*Festuca arundicacea* Schreb.) and smooth bromegrass (*Bromus inermis* Leyss), led to an expansion of cattle enterprises, with limited concern for effects on soil and plant productivity. In the 1950s, agricultural researchers, after noting the negative environmental consequences from decades of continuous grazing of introduced cool-season grasses, recommended soil fertility programs for pastures and planting diverse pasture mixes that included leguminous species. Improvements based on these methods led to a twofold increase in animal weight gains over unimproved pastures[3].

More recently, researchers[4] have argued that pasture system performance should be based on stability and system/existing resource interactions in contrast to productivity alone. Some argue that native species have been overlooked as a potential forage source in the tallgrass prairie region, because these species are typically found on the sites that have little opportunity for high yields[5], as native prairie species may be favored on soils with low

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nutrient availability[6–8]. Other studies suggest that warm-season grasses use phosphorus more efficiently than cool-season, introduced species such as smooth bromegrass[9]. Extant, native warm-season plant species have frequently been observed in cool-season pastures on resource-poor sites. Foster[10] found communities of native grasses restricted to low-productivity habitats and a strong competitive interference with establishment from the existing vegetation in more productive sites. These results and others[11] suggest that the establishment and survivorship of native species may be at a competitive disadvantage in high-productivity gradients.

Rosburg[12,13] inventoried ten pastures with similar soil and topographic conditions near the Marion County study site and enumerated seven native, warm-season grasses and 11 native forbs among seeded cool-season species, consistent with earlier work identifying various frequencies of native grasses, forbs and legumes[14]. Native, perennial warm-season grasses have been found to be drought tolerant and are highly productive during the summer season[15–17]. The native, warm-season grasses are C_4 grasses, which have a reduced photorespiration rate and a CO_2 uptake that is up to 40% higher than C_3 grasses, resulting in rapid sugar production and plant growth at high temperatures[18]. Because their productivity increases during the hot summer months when the cool-season species growth rates decline, native warm-season species are desirable candidates for integration into existing pastures. A Nebraska grazing study showed that rotating animals from cool-season to warm-season and back to cool-season paddocks resulted in higher average gain than leaving animals on cool-season grasses during the entire period[19]. Experiments rotating herds between native and introduced species in Iowa and other locations bore similar results[20,21]. Alternatively, the use of warm-season species in 'prairie pastures' or 'prairie paddocks' on marginal sites may match summer forage needs and serve landscape conservation functions as well.

Native plant species establishment

Studies have suggested events occurring during seed dispersal, germination and seedling establishment determine the fates of individual plants[22–24], and the environment and neighboring species immediately surrounding a seedling are critical in determining the composition of plant communities[10,25]. Thus, facilitating the conditions most amenable to native species germination and emergence is likely to facilitate successful establishment. Kemp and Williams[26] found that introduced cool-season grasses exploited resources more efficiently than native warm-season species, preventing the establishment of native grasses. In situations marked by such site preemption, dominant species may remain competitive under tolerance or suppression conditions[27], which suggests that changing competitive conditions through burning, tilling, mowing or grazing can shift competitive factors[27,28]. Suppression can include cultivating pastures and seeding the desired native species to facilitate establishment before cool-season species regrow[8,29], or using a non-selective herbicide, such as glyphosate, sprayed on germinating or newly emerging vegetation to provide a clean seedbed before seeding the warm-season species[30,31].

While both approaches rapidly prepare pastures for desired species establishment, each method has drawbacks: the use of tillage methods on marginal pastureland slopes may contribute to erosion, compromise soil quality and kill desired native species. When non-selective herbicides are used in pastureland, all species are reduced or eliminated[13,32,33] and residual herbicide may compromise the establishment of some seeded species[32]. Use of herbicides also limits marketing options for operators interested in raising and marketing their livestock as certified organic, as all land used for forage production must be free from prohibited substances such as synthetic herbicides for at least 3 years immediately prior to certification[34]. Mowing or grazing can serve as a substitute for herbicides. Davison and Kindscher[35] suggested that mowing or vegetation removal mimicked the effects of fire in decreasing plant competition. Diboll[36] and Old[37] showed a significant decrease in Kentucky bluegrass with mowing, and Johnson[38] diminished tall fescue populations with strategic mowing, but warm-season species may be susceptible to depleted carbohydrate reserves with untimely or repeated defoliation[39,40]. In general, forbs and many native legumes have an elevated apical meristem and are more susceptible to injury by defoliation[41].

Numerous studies have determined that good grazing management can transform poor grazing land into productive pasture[42], particularly if site suitability is emphasized[43]. The optimum grazing time for maximal forage quality, quantity and health for cool- and warm-season plant species has been determined to be the period between rapid growth and stem elongation/flowering[44]. Thus, grazing regimes can be successfully used for prairie establishment and maintenance if informed by forage phenology. In addition to competitive plant effects, abiotic conditions can influence prairie plant seedling establishment[45]. Adult, warm-season plant productivity was found to be strongly influenced by soil temperature[46–48]. Briggs and Knapp[49] and Peters[50] found precipitation to be a key factor in prairie seeding efforts.

Agroecological research problem and objectives

In the Marion County, Iowa, cow–calf operator group, a common theme repeated by the majority of participants was their belief in rotational grazing systems, where pastures are subdivided into paddocks and animals are moved from one paddock to another at appropriate intervals[51]. Rotational grazing systems ideally are designed to match the site specificity and carrying capacity of the land. In the course of the sociocultural analysis, one member of the study

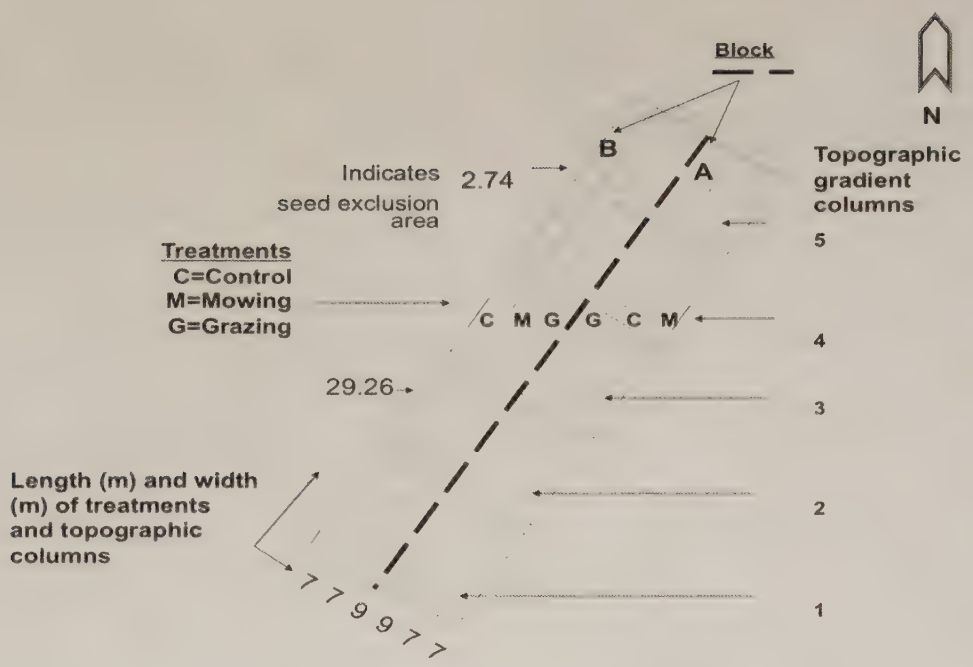

Figure 1. Prairie pasture experimental site with specified treatments in Marion County, Iowa.

group presented the opportunity to examine a rotational grazing system on his farm that would include native prairie plants (prairie pasture), thereby contributing to ecosystem services[52,53].

The agroecological research component at the farm and field level of this interdisciplinary project was based on the farmer's hypothesis that native prairie pastures could be developed to match site specificity while adhering to the family's farming system goals of protecting wildlife habitat and water quality, and nurturing plant diversity. They explained: '*We like to see a pasture with 40-plus species, because many plants take different minerals, grow at diverse times of the year. We want to graze year-round, and native warm season grasses and forbs are part of that mix.*' With the farm family, we developed the objectives of the agroecological study: (1) establish and monitor the growth and productivity of a prairie pasture system, with a goal of increasing biodiversity and sustainability in existing grasslands; and (2) determine which strategies—grazing, mowing or no management (control)—most effectively fostered native seeded species' growth relative to existing species suppression. Conventional protocols were replaced with ecologically based organic management practices to suppress undesired existing pasture vegetation while optimizing conditions for native species establishment. The on-farm site incorporated aspects affecting the whole farm management and farming system objectives[54] in order to develop recommendations that would be representative of regional dynamics with location specificity[55]. Such recommendations could be incorporated into existing or new USDA-NRCS (Natural Resources Conservation Services) programs supporting biodiversity and environmental quality on agricultural lands.

Study Area and Methodology: Agroecological Study

Experimental site

The prairie pasture experiment was conducted from 2003 to 2005 on a farm in southern Marion County that was in the USDA hardiness zone 5a[56]; located at 41°10′ latitude, 93°00′ longitude. The farm is characterized by the Gosport–Pershing–Gara soil association with gentle to steep slopes, and well drained to somewhat poorly drained soils formed in residuum from shale, glacial till and loess on uplands[57]. The experimental area consisted of a 40° northeast aspect and a 12% mean slope with dominant soils in the silty loam Clinton (alfisol) and Gosport (inceptisol) series. Prior to the experiment, the site was a fallow pasture dominated by tall fescue and other introduced pasture grasses and broadleaf species. No records or recollections of the site being plowed or row cropped were referenced, although portions of the land were severely eroded, suggesting previous soil disturbance. Infrequent native grasses, composites and legumes were present prior to the experiment. The site was surrounded by a deciduous forest and located near a first-order stream.

Site preparation

The experimental site covered an area of 46×160 m (Fig. 1). A prescribed burn was applied to the entire experimental area on April 24, 2003, when the majority of the dominant fescue was in mid- to late elongation, as per recommendations by Willson and Stubbendieck[58]. Vegetation on the experimental site and surrounding area (a perimeter of 10 m) was burned under a ring-firing technique[59]. Soil

Table 1. Native seed mix and seeding rate of certified southern Iowa local-ecotype varieties in prairie pasture planting, Marion County, IA.

Common name	Scientific name	Seed per ha	Percent of seed mix
Total grasses		567,562	72.61
Big bluestem	*Andropogon gerardii* Vitman.	238,995	30.58
Little bluestem	*Andropogon scoparius* Michx.	89,613	11.46
Indiangrass	*Sorghastrum nutans* (L.) Nash ex Small	238,954	30.57
Forbs		214,099	27.39
Legumes		180,643	23.11
Illinois bundleflower	*Desmanthus illinoensis* Michx.	66,906	8.56
Purple prairie clover	*Dalea purpurea* Vent.	100,360	12.84
Round headed bush clover	*Lespedeza capitata* Michx.	6,688	0.86
Showy tick trefoil	*Desmodium canadense* (L.) DC.	6,689	0.86
Composites		33,455	4.28
Maximillian sunflower	*Helianthus maximiliani* Schrad.	33,455	4.28
Total		781,661	

samples were collected from each experimental unit on April 30, 2003, and on May 24–25, 2005, following standard soil sampling procedures[60]. Soils were analyzed for phosphorus (Bray-1), potassium (Mehlich-3), calcium (Mehlich-3), pH (1 : 1) and organic matter at the Soil Testing Laboratory at Iowa State University (Ames, IA). VolcanaPhos® (Midwestern Bio-Ag, Blue Mounds, WI), an organic-compliant phosphorous source and lime ($CaCO_3$) were applied with a fertilizer spreader at a rate of 336 and 2242 kg ha^{-1} ECC, respectively, on June 18, 2003, based on the soil analysis results and farmer recommendations.

Prairie species seeding

A southern Iowa, local-ecotype, native species seed mixture (Osenbaugh Seed Company, Chariton, IA) was planted on May 15, 2003 with a 2.4-m Truax® no-till drill in 0.64 cm deep furrows and covered with soil. A designated area (2.73 × 46 m each) at six topographic positions along the slope of the experimental site was excluded from seeding to permit sampling of existing vegetation for prior existence of native species in the seed mixture. The seed mixture was composed of big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Andropogon scoparius* Michx.), indiangrass (*Sorghastrum nutans* (L.) Nash ex), Illinois bundleflower (*Desmanthus illinoensis* Michx.), purple prairie clover (*Dalea purpurea* Vent.), round headed bush clover (*Lespedeza capitata* Michx.), showy tick trefoil (*Desmodium canadense* (L.) DC) and Maximillian sunflower (*Helianthus maximiliani* Schrad.) (Table 1). The seed composition was selected on the basis of farmer preference, functional group diversity[61,62], documented mid- to late-summer palatability, life-cycle traits and historic presence in south–central Iowa. Seeding volume per species and in total reflected guidelines by NRCS[63].

Experimental design

An individual pasture of sufficient size to contain nine management plots was selected by the rancher–cooperator to serve as the experimental site. The site was delineated into two blocks measuring 23 × 160 m each; with each block containing three randomly assigned treatments of grazing, mowing or no management (Fig. 1). Superimposed on the treatments were five plots in a contiguous column from the base of the site to the apex of the slope, designed to determine trends at five topographic positions in each block. Plots receiving the mowing treatment or no management were 7 × 32 m, and plots receiving the grazing treatment were 9 × 32 m. Each plot included a 2.74 × 7 or 9 m (relative to treatment received) control non-seeded strip that was not seeded but received the treatment. Each non-seeded strip was separately sampled for the presence of extant native species and served as a visual comparator to the seeded areas.

Grazing management. The grazing treatment was designed to balance on-farm cattle management decisions with a management tactic. Cattle utilized in this experiment included Angus cows from the cow–calf operation. Cattle numbers varied from 5 to 24, based on the size of paddocks and pasture productivity (Table 2). A high-tensile, PVC-wire electric fence formed the perimeter of the grazing treatment area with polywire gates to regulate cattle entry. Flash grazing, a short-term grazing event at a high stocking density that improves the distribution of animals[64], and reduces animal selectivity, resulting in low defoliation heights and homogeneous grazing, was used. The grazing management decisions were predicated by water and time availability. Grazing intensity varied each year based on vegetation growth (Table 2).

Mowing management. The mowing treatment was designed and implemented with guidance from the local NRCS office. Mowing was conducted during rapid vegetative growth periods to avoid impairing plant health[65]. A combination of tractor-pulled and self-propelled rotary mowers was used to apply mowing treatments. The date and frequency of mowing was determined by observation and guided by NRCS literature. Mowing occurred when vegetation averaged 30–50 cm in height; mowed heights

Table 2. Grazing dates and management information in prairie pasture experiment during the 2003, 2004 and 2005 grazing seasons.

Date	Block[1]	Original vegetation height (cm)[2]	Length of grazing (h)	No. of head grazing
June 16–17, 2003	A	25.4–30.5	12 night hours[3]	24
June 17, 2003	B	25.4–30.5	12 night hours	24
October 7, 2003	A	25.4–76.2	12 night hours	24
November 7, 2003	B	25.4–76.2	12 night hours	24
June 4–16, 2004	A and B	60.9–76.2 (A) 63.5–88.9 (B)	120 night hours	5
July 20–30, 2004	A and B	35.6–40.6 (A) 35.6–152.4 (B)	120 night hours	5
June 16–20, 2005	A and B	15.2–91.4 (A) 15.2–76.2 (B)	96 h[4]	10

[1] A and B = Blocks A and B on northern and southern portions of the site, respectively.
[2] Immediate post-grazing plant height was not measured, due to high variability and heterogeneity within and among blocks and topographic positions.
[3] 'Night' indicates the time between 21.00 h and 9.00 h when cows were moved to experimental plots; cows were retained on surrounding pasture during the day.
[4] Block choice was not restricted and cows could enter any grazing treatment plots at any time (during the day or night).

were reduced to 8–18 cm, depending on conditions and year (Table 3). The mowed cuttings were left on the plots.

No management. After burning on April 24, 2003, the no-management treatment (control) remained unmanaged during the first 2 years of the experiment (2003–2004). On May 1, 2005, a prescribed burn following a ring-firing technique was executed to control unwanted species, according to the farmer–cooperator's specifications, but the area remained ungrazed and unmowed during the course of the experiment.

Table 3. Prairie pasture mowing dates and vegetation heights in prairie pasture experiment, 2003–2005.

Date	Original height (cm)	Mowed height (cm)
June 18, 2003	25.4–30.5	10.2
July 10, 2003	30.5–50.8	10.2
May 29, 2004	35.6–60.9	15.2
June 30, 2004	38.1–50.8	15.2
May 23, 2005	33.0–50.8	7.62

Data collection

Presence–absence and community inventory. Data collection included recording the presence or absence of a particular plant species, according to methods described by Vogel and Masters[66] by placing a 1 m^2 frequency grid in five random locations (matching topographic positions down the slope) within each treatment. Samples were taken within five 0.04 m^2 sub-quadrats per quadrat placement. Vegetative height was recorded for plants within each quadrat. The presence or absence (denoted as a 1 or 0, respectively) for each identifiable seeded species was recorded for each 0.04 m^2 sub-quadrat. In 2003, five observations (five sub-quadrats) were made within a one-quadrat sample for each of the five topographic positions within each treatment (total of 25 observations). In 2004, two quadrat samples yielded ten observations for each of the five topographic positions within each treatment (total of 100 observations), and in 2005, four quadrat samples yielded 20 observations for each of the five topographic positions within each treatment (total of 200 observations). The presence of each seeded species was analyzed as a percentage of total observations.

All species present in each of the five samples per quadrat were recorded in the July 2005 sampling period, yielding 20 inventories per topographic position. Species were identified using procedures developed by Stubbbenbieck et al.[67], Christiansen and Müller[68] and Barnes et al.[69], and were verified using taxonomic keys in Steyermark[70] and Rydberg[71]. The frequency of each identified species per sample was also recorded.

Biomass assessments. In August of each year, the existing vegetation height and biomass was measured. A 25×25 cm (0.1 m^2) quadrat was randomly placed within each topographic position, and all living and dead vegetation was cut within the quadrat at the ground level. Data were recorded from one quadrat per topographic position per treatment in 2003 and 2004, and four quadrats per topographic position per treatment were acquired in 2005. Biomass samples were dried for 72 h at 67°C and weighed. The mean dry weight was recorded for each sample.

Non-seeded topographic position measurements. For each non-seeded area, the presence or absence of seeded native species was measured within one randomly placed 1 m^2 quadrat per topographic position per treatment area. Five randomly placed 0.04 m^2 sub-quadrats were sampled for each seeded species. Each experimental site was surveyed in August 2003 and in August 2004. The percentage of each seeded species present in each experimental unit was recorded.

Radiation measurements. Solar radiation penetration through the vegetative canopy was measured with a LAI-2000 Plant Canopy Analyzer™ (LI-COR, Inc., Lincoln,

Table 4. Monthly mean temperature and precipitation totals during prairie pasture growing seasons in Knoxville, Marion County, Iowa, 2003–2005.

	May		June		July		August	
Year	Temp. (°C)[1]	Precipitation (cm)	Temp. (°C)	Precipitation (cm)	Temp. (°C)	Precipitation (cm)	Temp. (°C)	Precipitation (cm)
2003	15.56	10.49	20.56	16.36	23.33	4.01	24.44	2.44
2004	17.22	22.89	20.00	6.78	22.22	15.27	20.00	19.30
2005	15.00	6.58	23.33	13.41	24.44	8.26	23.33	3.94
54-yr mean[2]	16.67	10.77	22.22	11.33	24.44	10.52	23.33	10.11

[1] Iowa Environmental Mesonet, 2003–2005.
[2] Fifty-four-year mean:1951–2005.

NE). By using diffuse non-interceptance (DIFN), values between 0 and 1 were assigned, based on the probability of diffuse radiation from the upper hemisphere penetrating the canopy to a particular location. Four replications per topographic position were taken on days when the sun was obscured by cloud cover with a 90° view cap. This DIFN measurement was averaged by LAI-2000 software and recorded for each topographic position.

Weather conditions. Monthly mean precipitation and temperatures from the Knoxville, Iowa, NWS COOP Network climate station were acquired from Iowa Environmental Mesonet[72]. The Knoxville station was the closest location to the experimental site.

Data Analysis

All field data were analyzed using analysis of variance with mixed models[73]. Differences among treatments were obtained through least square means and statistically separated using Tukey's studentized range (HSD) means comparison test at $P \leqslant 0.05$ significance level.

Results and Discussion

Soil characteristic effects

Soil analysis determined low P content, averaging 2.9 ppm, and low K content, averaging 107 ppm[74]. Compared to the more fertile soils in Iowa, soils at the experimental site were considered to be low in organic matter, averaging 3.7%[57], and signifying marginal grain crop suitability.

Weather effects

During the 2003 season, above average precipitation occurred in June, followed by a drought period in July and August with rainfall substantially below the 54-year (1951–2005) mean precipitation (Table 4). This low-rainfall period might have impacted native seedling establishment, as previous studies have determined that soil moisture is critical to successful species emergence and establishment[75,76]. Low moisture also may have caused significant stress and mortality among the newly emerged species, and may have favored individuals in microsites that conserved moisture through shade or litter[77,78]. During the months of May, July and August 2004, precipitation was above 54-year mean levels, but in May, July and August 2005, precipitation was again below average levels. Temperatures throughout the experimental years were generally equivalent to the 54-year average temperature and suitable for native plant growth (Table 4).

Native plant establishment and community inventory

Seeded native grass and forb species were successfully incorporated into existing pasture in all treatments in this experiment. Identifiable species in the prairie pasture in the first year (2003) included only native grasses, Illinois bundleflower and purple prairie clover. In 2004 and 2005, all seeded species were observed. As previously mentioned, several months of low rainfall accompanied by high temperatures appeared to impact the establishment and survival of native species, with variable responses, based on species and year, described in the next section.

Extant native prairie species populations. Background presence of native species in experimental plots prior to treatment application was not significant in all years of the experiment (data not shown). Of all the native species, native grasses (specifically big bluestem and indiangrass) predominated, but were present in only 4% of samples in control strips, with other species similarly absent or sparse across all treatments and topographic positions. Thus, extant native populations did not impact the evaluation of experimental management techniques.

Seeded native prairie species populations. Seeded prairie species successfully established in all three treatments in 2003, but the frequency of seeded native species declined in the grazing and control treatments from 2003 to 2005, with a numerical, but not statistical, increase in the mowing treatment (Fig. 2). By the end of the third year of the experiment, native species were observed in 65% of samples in the mowing treatment and ≈ 50% in the control and grazing treatments. The overall frequency of seeded legume species was ≈ 55% in July 2003, and by August 2005, native legumes were present in 22% of control

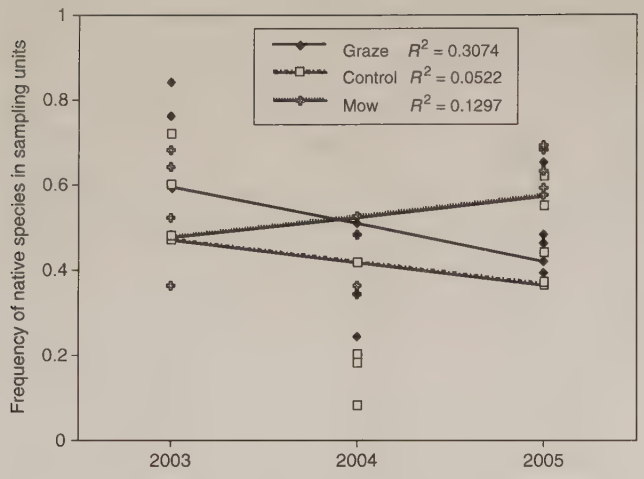

Figure 2. Frequency of total native species presence under three management treatments in the prairie pasture experimental site in Marion County, Iowa, 2003–2005.

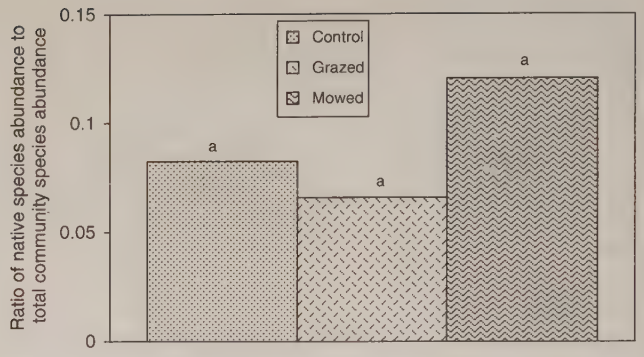

Figure 3. Native species relative abundance under three management treatments in the third year after seeding in the prairie pasture experimental site in Marion County, Iowa, 2003–2005.

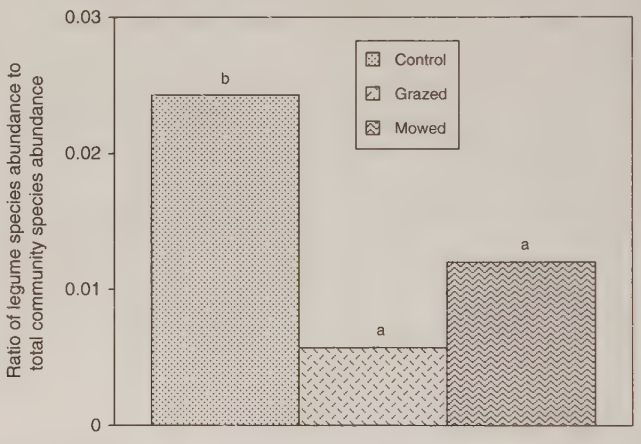

Figure 4. Native legume species relative abundance under three management treatments in the third year after seeding in the prairie pasture experimental site in Marion County, Iowa, 2003–2005.

treatment samples, 10% of mowing treatment samples and 7% of grazing treatment samples. The seeded native grasses increased from 2003 and 2005 in the grazed and mowed plots, and by August 2005, native grasses were present in 61% of mowing treatment samples, 46% of grazing treatment samples and 36% of control treatment samples. Although the native species were a small part of the total pasture community, with no significant differences in this ratio among the three treatments (Fig. 3), their presence was notable, particularly during July and in blooming periods.

Grazing treatment. In the grazing treatment, seeded native species declined over the 3 years of the experiment (Fig. 2), varying in population size over the months and years of the experiment. Native species populations were lower in the grazing treatment compared to the control in all months, except in July 2004 (Fig. 4), and native legumes were specifically diminished. Specific legume and forb species varied in their response to treatments, with Illinois bundleflower and purple prairie clover initially at the highest frequency in the grazed treatment in the first year, but declining to negligible levels by the third year (data not shown). Bush clover populations were consistently lower in grazed plots compared to the other treatments. Similar populations of tick trefoil and Maximillian sunflower were found in the grazed and mowed plots throughout the years of the experiment.

In the pasture community structure census, the relative abundance of introduced agricultural grasses in the grazing treatments was significantly higher than all other treatments (Table 5). Abundance of the total legume species (Table 5) and species richness (Table 6) were intermediate to the control and mowed treatments, with no significant differences noted among treatments. The grazing treatment had the highest DIFN, representing the most open canopy among treatments in 2004 and in 2005, when it was significantly greater than the other treatments (Table 6). The overall vegetative biomass was not significantly different among the treatments (Table 6).

Mowing treatment. In the mowed plots, total seeded native species populations remained stable throughout the experiment compared to declining populations in the other treatments (Fig. 2), but the relative abundance of native species did not differ from the other treatments. The mowing treatment tended to have the highest relative abundance of native grasses in the pasture community among all treatments, with a trend ($P \leqslant 0.12$) toward higher populations than the control treatment. The frequency of native grass species was significantly greater in the mowing and grazing treatments compared to the control treatment in July 2004 and in August 2005, as grasses were observed most frequently in the final sampling periods.

Seeded native legume species, however, declined under the mowing regime. The frequency of seeded legume species was similar to the grazing treatment and significantly lower than the control at the June 2003 and July 2005 sampling periods, and lower than the grazed treatments in August 2003 ($P \leqslant 0.09$) (data not shown).

Table 5. Plant community components in the third year after seeding native prairie species in the pasture prairie experiment, Marion County, Iowa, 2005.

Treatment	Introduced grass relative abundance[1]	Ratio of native legumes to introduced species[2]	Ratio of native legumes to introduced legumes[3]	Relative abundance of total legumes[4]
Control	0.19c[5]	0.09a	0.34a	0.30
Grazing	0.24a	0.02b	0.05b	0.36
Mowing	0.22b	0.03b	0.09b	0.38
P-value	0.0026	0.0104	0.0027	0.0801

[1] Introduced grasses defined as tall fescue, smooth brome, Kentucky bluegrass and orchardgrass.
[2] Introduced species defined as tall fescue, smooth brome, Kentucky bluegrass, orchardgrass, white clover, red clover, birdsfoot trefoil and alfalfa.
[3] Introduced legumes defined as white clover, red clover, birdsfoot trefoil and alfalfa.
[4] Total legumes defined as Illinois bundleflower, purple prairie clover, bush clover, tick trefoil, white clover, red clover, birdsfoot trefoil and alfalfa.
[5] Means within each column not followed by the same letter are significantly different according to Tukey's difference of the least square means at $P \leqslant 0.05$; *P* value stated otherwise.

Table 6. Vegetative cover characteristics and species richness in prairie pasture experiment in 2003, 2004 and 2005, Marion County, Iowa.

	2003		2004		2005		
Treatment	DIFN[1]	Biomass (g m^{-2})	DIFN	Biomass (g m^{-2})	DIFN	Biomass (g m^{-2})	Species richness[2]
Control	0.18b[3]	208.7	0.09b	406.4	0.14b	406.9	29.0a
Grazing	0.25b	291.2	0.43a	243.7	0.27a	312.8	24.4ab
Mowing	0.46a	128.9	0.34a	289.9	0.20b	302.5	22.6b
P-value	0.0418	NS	0.0213	NS	0.0138	NS	0.0331

[1] Diffuse non-interceptance measurement (higher values indicate greater light penetration).
[2] Mean species richness per 0.04 m^2 quadrat sample.
[3] Means within each column not followed by the same letter are significantly different according to Tukey's difference of the least square means; NS, Not significant at $P>0.05$; *P* value stated otherwise.

The abundance of native legume species was significantly lower in mowed plots than in the control after 3 years (Fig. 4). In the pasture community structure census, the relative abundance of *native* legume species was significantly lower than the control treatment. The relative abundance of introduced agricultural grasses was significantly greater than the control, but lower than the grazing treatment (Table 5). The mowing treatment had the same species richness as grazed plots. The mowing treatment had the highest DIFN in 2003, and a DIFN intermediate to the grazing and control treatments in 2004 and 2005 (Table 6).

Control treatment. When plots were left unmanaged, with the exception of controlled burns in 2003 and 2005, seeded native species, particularly native grasses, declined over the 3 years of the experiment, tending to occur at the lowest frequency compared to the other treatments in 2004 and in August 2005 (data not shown). Native legume species, however, tended to appear most frequently in the control treatment. The frequency of legume species was significantly higher than all treatments in June 2003 and July 2005. Native legume species' relative abundance was significantly greater ($P \leqslant 0.05$) compared to the mowing and grazing treatments by the end of the third year (Fig. 4). In the pasture community structure census, the abundance of introduced agricultural grasses was significantly lower than all treatments (Table 5).

Integration of treatment effects. The establishment of native prairie plants in an existing pasture was mitigated by several biotic and abiotic factors. Interspecific competition among diverse community members, including preemptive or overgrowth competition[79], may have impacted native species establishment, as neighboring species competed for radiation and soil resources, leading to reduced photosynthetic capacity and growth. The native legumes experienced preemptive and overgrowth competition, with morphological and physiological features limiting opportunity to overcome competition. Their determinate growth trait, in which stem growth ceases upon shoot apices developing into inflorescences, prevents strong persistence under defoliation[80]. In addition, in upright perennial forbs, the shoot apex is located at the top of plant and, when removed, the plant must regrow from axillary buds at the base of the stems, at significant energetic cost to the plant[80]. In the mowing and grazing treatments, the legumes consistently experienced defoliation, whereas in the control

treatment, the overgrowth and competition of the surrounding vegetation may have been less prohibitive to survivorship than the stresses of the vegetative removal treatments. The stress was great enough, however, to prevent high native legume or grass species abundance in the control.

Bush clover, tick trefoil and Maximillian sunflower populations were not visible in quadrat samples in the first year after seeding. By 2005, bush clover appeared in 8% of sampling units in the control, 3% in the mowing and 1% in the grazing treatments, and tick trefoil appeared in 13% of all sampling units in the control and 4% of grazing and mowing treatments' samples. Maximillian sunflower was located in 10% of the control, 1% of the grazing and 2% of the mowing treatments' sampling units by the third year. The increased abundances of these seeded native plants from 2003 to 2005 may have been related to delayed germination until the second season, as Maximillian sunflower and tick trefoil typically undergo germination after successive cold–dry and warm–moist stratification periods[81], establishing several years after seeding[82]. Bush clover also germinates after a combination of cold–dry stratification and acidic scarification[81] and may have survived better in this experiment due to its ability to compete with grasses[83].

In the prairie pasture system, cattle grazed both native and introduced plant species, but seemed to prefer introduced, cool-season grasses. Community richness in the grazing treatment was intermediate to the control and mowing treatments, similar to other studies on the effect of grazing on plant community composition. Damhoureyeh and Hartnett[46] observed a competitive release of subdominant species from grazing of dominant species, leading to heterogeneous patches with fewer dominant species, increased light penetration and warmer soil temperatures. Hartnett et al.[84] also found greater micro-site diversity as a result of preferential cattle grazing behavior, although in our experiment, the overall low community richness was associated with high DIFN and an open plant canopy in the grazed plots.

Native grasses, however, were the most abundant in the grazing and mowing treatments compared to the unmanaged control. Numerous studies have correlated high light penetration to greater germination[85] or emergence of grass seedlings[86], as well as successful grass seedling establishment associations with low leaf litter and lack of neighbor presence[22,87,88], as observed in the prairie pasture.

Although studies have correlated the light penetration facilitated by mowing to increased community richness[89], our results suggested that the non-selective elimination of biomass through mowing pushed the system toward lower community richness. Mowing plants at or below 24 cm, the average height of the native legumes' apical meristems, may have been detrimental when applied during pre-bud and early reproduction stages and, thus, reduced the absolute and relative abundance of native legume species in this treatment. The creeping stolons and prostrate morphology of several introduced agricultural legumes, alternatively, may have persisted under mowing conditions contributing to high *total* legume abundance in the mowing treatment[44].

The highest absolute and relative abundance of legume species in the control treatment corresponded with low DIFN, greater community richness and low relative abundance of introduced agricultural grasses. Wilson et al.[78], and others[77] have suggested that vegetation and litter ameliorated moisture stress, outweighing light availability for successful establishment of seedlings under stressful abiotic conditions. The community richness observed in control plots was consistent with some studies but contrasted with others. Foster and Gross[22] and Tilman[90] determined that decreased light penetration caused by litter increased mortality and decreased species richness. However, Wilsey and Polley[76] found that litter removal affected seedling emergence but that decreasing light availability did not decrease plant diversity, as we observed in our experiment.

Conclusions from the Agroecological Study

Establishment of native plant species and prairie pastures in an organic setting

Researchers generally view native species dynamics: (1) as components of natural native species communities exhibiting reactions and interactions with plant neighbors, disturbances and biophysical events; (2) as extant individuals within hostile environments, sustained by niches or disturbances; or (3) as seeded species establishing in sterile environments under substantial experimental control, mandating sowing in a competition-free and clean seedbed obtained through herbicide application or tillage[31,78]. This experiment contributes to a new view for native species community dynamics under management tactics that are feasible for farmers in working agricultural landscapes. The results presented here suggest that the establishment of native species, sown into existing mixed pasture, can be achieved without the use of herbicides. Burning the pasture prior to sowing native species, however, was shown to be critical for successful establishment, following results from previous research[21,40,58]. While native species thrived in the control treatment, grazing and mowing also were shown to suppress cool-season grasses, allowing the native warm-season species to survive. These results suggest that in a low-productivity, partially stressed and frequently managed pasture community, existing dominant species can be adequately suppressed to allow establishment of new species. Weather factors, however, including the initial drought period following prairie seed planting, most likely led to a reduced establishment rate for the native species. With the abundance of native grasses and total native species equivalent among treatments, all treatments similarly affected the pasture community in relation to native

grass and total native species establishment. Legume species relative abundance, however, differed among treatments, with the control treatment exhibiting higher legume relative abundance compared to the other treatments.

This research initiated an understanding of the potential for seeding native species into existing pasturelands without herbicides. Future research, as articulated by the farmer–cooperator, could include the impact of irrigation on native species establishment and growth in prairie pastures; the potential of 'fallowing' first-year prairie pastures to facilitate maximum native species establishment before grazing; and an analysis of the feed value of native species present in these systems.

Project conclusions and recommendations

Innumerable pasture acres throughout Iowa yield multiple benefits on the farm and community level, in terms of livestock production, resource conservation, biodiversity enhancement and native ecosystem preservation. Such pasture systems are strong candidates for native species preservation, due to soil and site characteristics, as soils under native prairie have low nutrient availability relative to modified systems dominated by introduced species. Despite encroaching urbanization in the Marion County, Iowa, cow–calf systems and their pasture base continue to provide significant opportunities to contribute to native habitat diversity. Factors affecting grassland implementation and improvement are multifaceted, however. According to the Marion County agricultural agency officials, matching site conditions with appropriate pasture management was viewed as a challenge for most producers, requiring additional educational and program support[91]. Additionally, the idea of prairie pastures was novel and untested in their estimation. Although economic analysis was not a component of this specific prairie pasture establishment research, we can extrapolate potential economic benefits from a review of the organic and grass-based cattle literature. According to Acevedo et al.[92], annual costs for organic grass-legume pastures averaged \$281 ha^{-1}, which were greater than conventional feed costs. Selling organic hay, after herd needs are met, however, was found to garner organic operators a 10–30% premium over conventional hay prices. Provided certified organic regulations are followed from the last third of the cow's gestation period and herd health is maintained through organic-compliant treatments, organic beef sales combined with organic hay sales from cattle raised in a prairie pasture system could add to the farm's overall economic viability. The proposed system also offers risk reduction by diversification of product sales and timing of income.

Cow–calf operators identified through the sociocultural study, who were interested in protecting remnant species on their land and practicing environmental stewardship by avoiding plowing or herbicides would be ideal candidates for prairie pasture systems. In pursuing the organic, grass-finished beef market, the farmer–cooperator in the prairie pasture experiment reiterated his motivation, '*Our first priority is to keep our farm wild. Our second priority is to get an ecological profit.*' He concluded, '*Farmers with a land ethic are hidden...but they're growing.*' A better understanding of these diverse farming systems and farmers' motivations for protecting biodiversity, and documentation of the economic value of environmental services obtained from grass-based and organic cow–calf operations can contribute to the formulation of more effective agricultural policies. Incorporating native grasses and forbs into otherwise marginal rangeland or pasture falls within the mandate of the Conservation Stewardship Program (formerly the Conservation Security Program) ('CSP') as authorized in the US Farm Bill (Food, Conservation and Energy Act of 2008). Government programs, such as the CSP and EQIP, can provide incentives for sustaining a farm landscape consisting of diverse, grass-based agricultural systems that support rural livelihoods and environmental quality. Plans for repeating this study on other farms in Marion County are underway in order to develop additional recommendations for ecologically based, organic cow–calf operations.

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Influence of field margin type on weed species richness and abundance in conventional crop fields

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Abstract

Natural vegetation occurring on farms in field margins, fallow fields, ditch systems and neighboring forests, provides increased biodiversity, structural diversity, habitat for wildlife and beneficial insects, and can act as a protective buffer against agrochemical drift. Nevertheless, farmers frequently view these areas as non-productive and as potential sources of weeds, insect pests and diseases. Weed species richness and abundance were examined in crop fields in 2002–2003 at the Center for Environmental Farming Systems near Goldsboro, NC to determine if crop field weed infestation was associated with field margin management (managed versus unmanaged). Weed species abundance and richness were measured over two growing seasons on four occasions in crop fields along permanent transects that extended from the field edge toward the center of the field. The presence/absence of data for all plant species in the field margin was also recorded. For both margin types, managed and unmanaged, more weeds were found near the field edge than in the center of the field. Weed species richness was slightly higher in cropland bordering managed margins than in cropland along unmanaged margins. Several significant interactions led to an examination of nine dominant weed species in each field margin type and their distribution in crop fields. When all sampling dates were pooled, only 42 (40%) of 105 species identified in the field margins were observed in the crop field. Managed margins had lower species richness than unmanaged field margins—less than half the mean number of species (15 versus 6 species, respectively). Contingency table analysis did not reveal any association between plant species occurring in the margin and those found in the crop field. Furthermore, margin type and weed presence in the field margin were not effective predictors of weed occurrence in the crop field as determined by logistic regression.

Key words: field margin, weed populations, crop edges, farm natural areas

Introduction

Agroecosystems are normally composed of interacting dynamic systems including managed agricultural land and unmanaged natural vegetation. Ecotones, the transitional areas between two different ecosystems, are unique because they usually possess physical characteristics and species from both bordering ecosystems. The field margin ecotone may be one of the most important aspects of farm landscapes for wildlife, insect and plant conservation, potentially contributing more to support biodiversity than either of the two bordering ecosystems[1].

Field margins (managed and unmanaged) are the most common natural habitat on farms (Fig. 1). They may be composed of a boundary zone, margin strip and farm track (if present), and the field and crop edges[2]. Boundary areas can include fallow fields undergoing plant succession, ditch systems, forests, fencerows, streams or formal hedgerows.

On farms, field margins provide increased biodiversity, structural diversity, habitat for wildlife and beneficial insects, and can act as protective buffers against agrochemical drift[3–8]. Nevertheless, farmers are reluctant to leave natural vegetation, and these areas have been declining over the last several decades, largely due to agricultural

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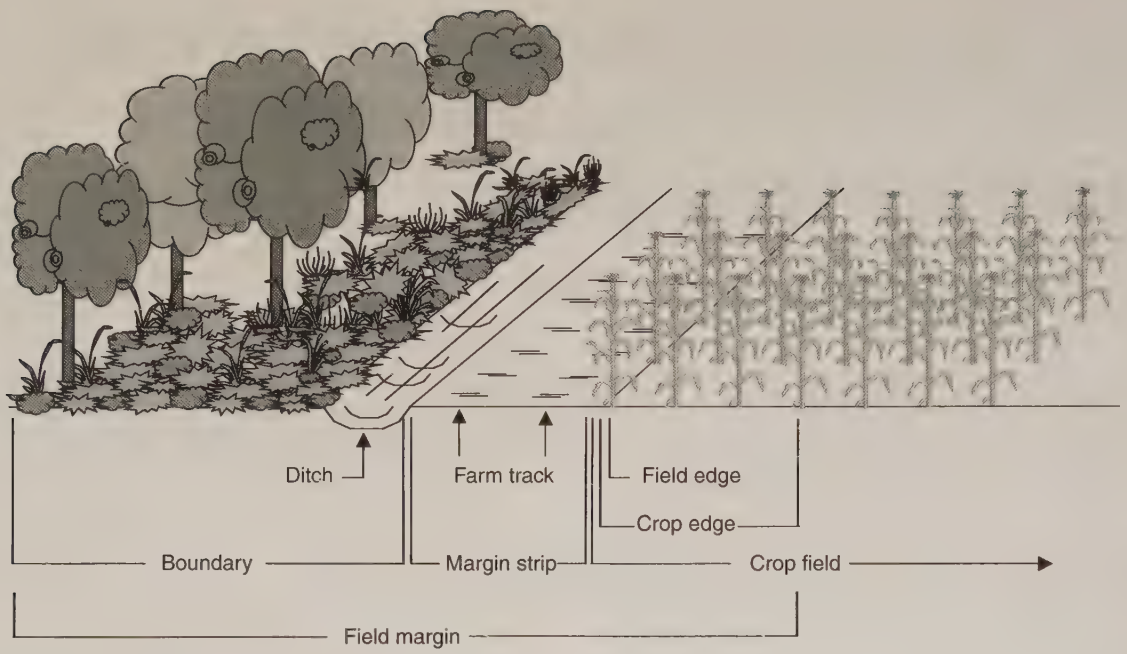

Figure 1. Principal components of field margins.

intensification. Contemporary farmers are cultivating larger fields and thus reducing the total area of field margins. Also, the use of synthetic fertilizers and pesticides has been found to significantly affect species richness and abundance in field margins[8,9].

Farmers have often viewed field margins as reservoirs for weeds, insect pests and diseases[5,8,10]. Some empirical studies have shown that weeds occur at highest densities in the crop edge, and it was assumed that this high abundance was due to field margin weeds invading adjacent crop land[10,11]. Investigations conducted to determine if and how weeds invade crop fields from the field margin[12] found a strong association between allele frequencies of *Bromus sterilis* species in field margins and in adjacent crop fields, indicating that the populations were genetically similar and suggesting that field margins contributed weeds to the crop field. In mid-western USA, Sosnoskie et al.[13] found that elevation gradient and field shape were important factors not under the direct control of farmers that influence weed species diversity in field margins. In Canada, Boutin et al.[14] reported that management practices of hedgerows and adjacent crop fields were mostly responsible for the abundance of weeds in hedgerows and field margins. Natural hedgerows contained many non-weedy, perennial plant species, while in planted hedgerows about 50% of the plant species were weeds[14].

In the last century, the practice of 'clean farming' was thought to be a remedy for the perceived dangers of leaving natural vegetation in the 'farmscape'. Weed management in the field edge can be time consuming and expensive for farmers who may not have the proper equipment, such as specialized mowers and sprayers, to manage them[5]. Also, it has been suggested that more intensive management can actually lead to exacerbating the weed problem. Most agronomic weeds are successful colonizers, and so regular disturbance of the field margin may increase weed abundance[15].

Field margin research: implications for agriculture in southern USA

Most field margin research has been conducted in western Europe, and so data for North American 'farmscapes' are scarce and little or no data are available pertaining to southeastern USA. The goal of our research was to assess the relationship between plant assemblages occurring in unmanaged margin strips and areas of natural vegetation and the populations of weedy plant species in neighboring crop fields. While European research has focused on field margins with formal hedgerows as the boundary, our research examined boundary areas of natural vegetation more common in southeastern USA (fallow fields, ditch systems and neighboring forest). These field margins were compared with those where the margin strip was regularly managed (by mowing or herbicide application) and the boundary was shared by another crop field.

Our objectives focused on conditions common to many farms in southeastern USA, but were specifically applied to conditions at the Center for Environmental Farming Systems (CEFS). Over the last several years, farm staff and researchers have conjectured as to whether boundary areas of natural vegetation on the farm (especially the old field successions) were contributing weeds to the adjacent crop fields. We wanted to examine the general hypothesis that more weeds are present in crop field edges, because they are present in field margins and specifically to assess: (1) if crop edges adjacent to unmanaged field margins are associated with higher weed species richness and abundance

than crop edges bordering managed areas; (2) how weeds are distributed in crop fields with respect to distance from the field edge; and (3) whether the presence of weedy species in the field margins and boundary areas can be used to predict weed levels occurring in these areas and the presence of the same species in the crop field.

A clearer understanding of the relationship between plants in the field margin and weeds in the crop field will help in the development of management recommendations for control of potential pest problems originating in the ecotone between natural and managed ecosystems.

Materials and Methods

Research site

Research was conducted in the Farming Systems Research Unit (FSRU) at the CEFS near Goldsboro, NC[16]. The CEFS is located (35.4 north latitude, 78.1 west longitude, 41 m above sea level) within one of the major river systems of North Carolina. The Koppen climate classification is Cfa, humid, subtropical. Soils are mainly Ultisols with considerable variation in type and distribution. The dominant soil type within each replication (diagnostic soil) was either Wickham (fine-loamy, mixed, semiactive and thermic Typic Hapludult) or Tarboro (mixed, thermic and Typic Udipsamment). The design at the FSRU is a randomized complete block with three replications of five farming systems. The agricultural production systems include a conventional system with best management practices (BMP) currently used by farmers, an integrated crop and animal system and an organic system. The two remaining systems are a successional ecosystem (old field succession) and a plantation forestry/woodlot system of commercially valued forest species[14]. The successional areas had been fallowed since the winter of 1998 when they were planted to a rye (*Secale cereale* L.) cover crop. The experimental site was approximately 81 ha with individual fields ranging in size from 0.8 to 4 ha. Some of the fields on the FSRU are bounded by forest. The FSRU is also drained by a large ditch system.

Field selection and sampling procedure

Four fields were selected in the FSRU bounded by a large area of natural vegetation (old field succession, ditch system, or forest) on one side and adjoined a crop field on the other side—thus representing two types of field margins ('unmanaged' and 'managed', respectively). Each rectangular field was greater than or equal to 1.5 ha. Two more fields were selected that contained only one of the above field margins. One field had an unmanaged boundary and an unmanaged margin strip; the other field ran parallel to a managed boundary and had a managed margin strip. In all, ten field margins were selected for study: five along unmanaged margins and five along managed margins. Field histories for these fields beginning in 1999, when the FSRU was initiated are presented in Table 1.

Perpendicular to each of the ten field margins, five permanent transects spaced 10 m apart were established with sampling points set at 1, 3, 7, 15, 30 and 50 m from the field edge[2] (Fig. 2). At each sampling point, a 0.30×0.75 m quadrat was placed perpendicular to the row closest to the transect point and on the neighboring row on each side. Numbers of each weed species were recorded (i.e., three quadrat observations at each transect point). These observations were later combined resulting in a measured area of 0.675 m^2.

Field margin vegetation

Farm tracks between crop fields were mowed (or in previous years sprayed with nicosulfuron applied at 1.68 kg [ai] ha^{-1}) 2–3 times per season. Margin strips between unmanaged boundaries and crop fields were allowed to grow unrestricted for the duration of the cropping season. After crop harvest, these areas were mowed to the edge of the boundary.

In addition to the aforementioned sampling points in the crop fields, transects were extended away from the crop field and into the margin strips and boundaries. Additional sampling points were set at −2.5, −5 and −8 m from the field edge to the margin strip and boundary (Fig. 2). These distances allowed observations to be made in the center of the farm track, inside the unmanaged boundary area and well inside the unmanaged boundary. For managed margins, observations were taken at the center of the farm track. At each of these points, a 0.75 m^2 quadrat was used in collecting species richness as presence/absence data.

Field management and sampling dates

Within each year, all fields were planted with the same crop under conventional tillage practices. Maize (*Zea mays* L.) was planted in 2002 and peanut (*Arachis hypogaea* L.) in 2003. Herbicides were neither used prior to spring sampling dates nor for at least 6 weeks before the fall sampling date (Table 1). This procedure allowed spring weeds to germinate and be counted before any herbicides were applied and permitted sufficient time (6 weeks) from application to the fall count in September so that residual effects of the herbicides applied earlier had disappeared.

On April 17, 2002, Dekalb 687 Round-Up Ready® maize was planted in conventional-till, BMP fields on 0.76 m rows. On May 6–7, fields were censused for weed abundance and species richness and data were collected in each margin type and transect. Herbicide (glyphosate) was applied on May 8. No herbicides were applied to the fields after May 23. Maize was harvested on September 7–9, 2002 and transect data were collected again 2 weeks after harvest on September 21–22.

In 2003, fields were disked on April 10 and 3 weeks later on May 1–2 fields were sampled for weed abundance and species richness with no crop present in the field. Sampling in 2003 was scheduled to complete counts before peanut fields were to be planted and sprayed with the

Table 1. Field histories of fields selected for data collection at the FSRU of the CEFS, Goldsboro, NC.

	Pre-experiment field histories[1]		
Field	**1999**	**1999–2000**	**2001**
	Crop[2] (cultivar)		
5	Corn (DK-714)	Peanut (NCV-11)	Cotton (Sure Grow 747)
13	Corn (DK-714)	Peanut (NCV-11)	Cotton (Sure Grow 747)
23	Corn (DK-714), Wheat (C9704) →	Wheat/Soybean (Hartz 6686-RR)	Cotton (Sure Grow 747)
19	Corn (DK-714), Wheat (C9704) →	Wheat/Soybean (Hartz 6686-RR)	Cotton (Sure Grow 747)
42	Corn (DK-714), Wheat (C9704) →	Wheat/Soybean (Hartz 6686-RR)	Cotton (Sure Grow 747)
43	Corn (DK-714)	Corn (DK-714)	Soybean (NK S57-A4)
	No. of applications (H = herbicide, I = insecticide, F = fungicide, D = defoliant, GR = growth regulator)		
5	1H	2H	2H, 1I, 1D, 1GR
13	1H	2H	2H, 1I, 1D, 1GR
23	2H	2H	2H, 1I, 1D, 1GR
19	1H	1H	2H, 1I, 1D, 1GR
42	2H	2H	2H, 1I, 1D, 1GR
43	2H	4H	2H, 1I, 1D, 1GR
	Experimental period for data collection		
Field	**2002**	**2003**	
	Crop (cultivar)		
5	Corn (DK-687 RR)	Peanut (NCV-11)	
13	Corn (DK-687 RR)	Peanut (NCV-11)	
23	Corn (DK-687)	Peanut (NCV-11)	
19	Corn (DK-687)	Peanut (NCV-11)	
42	Corn (DK-687)	Peanut (NCV-11)	
43	Corn (DK-687)	Peanut (NCV-11)	
	No. of applications (H = herbicide, I = insecticide, F = fungicide, D = defoliant, GR = growth regulator)		
5	1H, 1I	5H, 1I, 1F	
13	2H, 1I	5H, 1I, 1F	
23	3H, 1I	4H, 2I, 1F	
19	2H, 1I	3H, 2I, 1F	
42	2H, 1I	2H, 2I, 1F	
43	2H, 1I	1H, 1I, 1F	

[1] **Cultural practices:** Limestone and fertilizer applied according to soil test recommendations.
Tillage: In 1999, all fields received pre-plant disk, chisel and field conditioning. Field 5 received 1 in-row cultivation post-plant.
In 2000, fields 5 and 13 were disked and chisel plowed prior to planting, whereas the remaining fields disked and field conditioned. Field 43 also received one in-row post-plant cultivation.
In 2001, all fields were disked, chisel plowed and field conditioned prior to planting.
Fields in corn in 2002 were disked prior to planting. In 2003, fields were disked and bedded for peanut and received one in-row cultivation.
[2] **Crops:** *Zea mays* L., *Triticum aestivum* L., *Glycine max* (L.) Merr., *Arachis hypogaea* L., *Gossypium hirsutum* L.

pre-emergence herbicide metolachlor. After all counts had been made, peanuts were planted and sprayed during the first week of June in raised beds on 0.97 m rows. No fields received herbicide application after July 8, 2003. Transect data were sampled again on September 7–8, 2003, just before the peanut canopy had completely closed over the rows.

Statistical analysis

Weed species abundance was compiled by the field, margin type (managed or unmanaged), transect, distance from the field edge and sampling date. The total counts for all species were analyzed using a stripped split-plot analysis of variance with PROC GLM[17] on square root transformed data. Because of the different histories, fields were treated as levels of a fixed factor, so that conclusions are limited to the fields used in this study. Thus, the field and margin type were whole plot factors, with transects providing replication within each field by margin combination. Distance from the field edge was the subplot factor and date was treated as stripped across other factors. Mixed model F Tests were obtained by including a RANDOM statement with transects within field and margin type, distance by transect in field and margin type and date by transect in field and margin type.

Data sets were summarized by margin type and date, and nine dominant species were selected for further individual analysis: *Amaranthus retroflexus* L., *Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster, *Cyperus esculentus* L., *Digitaria sanguinalis* (L. Scop.), *Ipomoea* spp., *Lamium amplexicaule* L., *Mollugo verticilliata* L., *Senna obtusifolia*

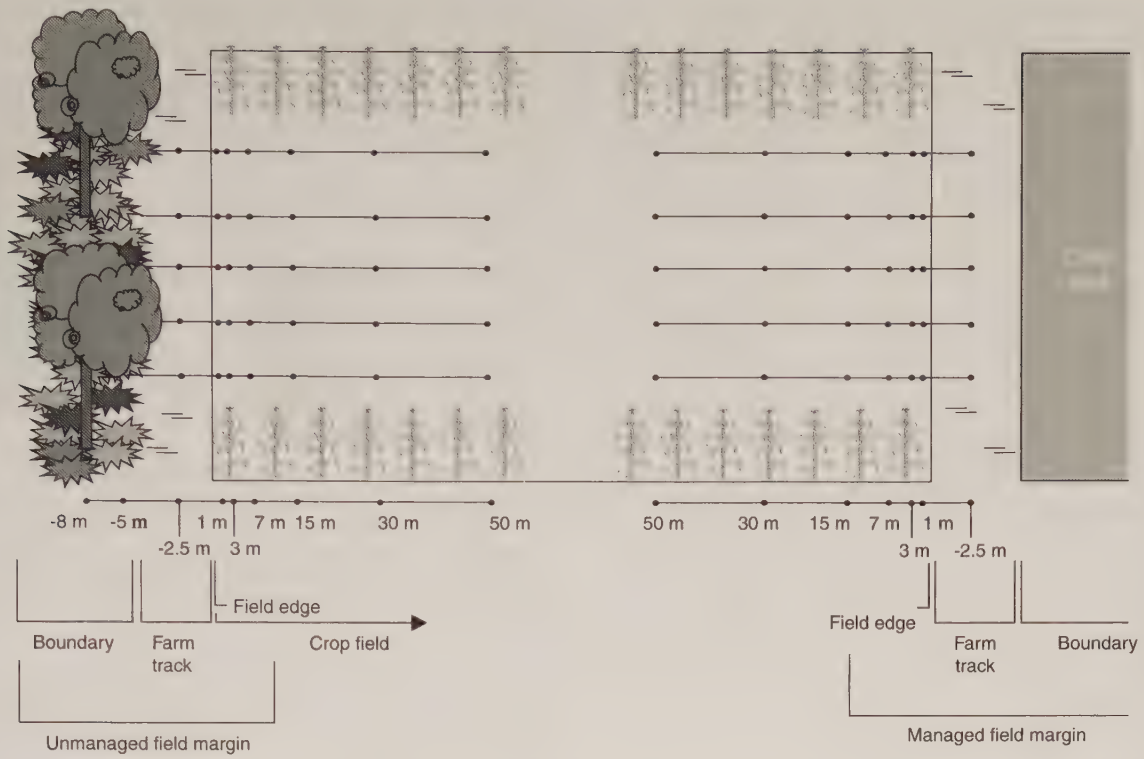

Figure 2. Diagram of field sampling points in crop fields and field margins at the FSRU of the CEFS, Goldsboro, NC, 2002–2003.

L. and *Sida spinosa* L. No attempt was made to differentiate between *Ipomeoa* species. Dominant species were chosen based on abundance, consistent presence for both margin types and consistent presence over sampling dates. Similar analysis of variances (ANOVAs) were carried out on square root transformed counts for each dominant species.

Species richness (the total number of species encountered in a sample) was determined for weed species in the crop field and for plants found in the field margin and results were analyzed with PROC GLM. ANOVA on species richness was carried out separately for the crop field and field margin. Data for species richness and abundance for weeds in the crop field were then combined into two distances: near the field edge (including distances of 1, 3 and 7 m sampling points) and near the field center (15, 30 and 50 m sampling points). Shannon's species diversity index[18] (relationship between the number of species and number of individuals) was calculated from transect data in each of the two crop field regions (field edge and field center) and values were analyzed according to the stripped split-plot ANOVA.

To determine whether an association existed between weeds appearing in the field margin and presence in the crop field, for each species, weed abundance in the crop field for each transect was converted to presence/absence data and paired with presence/absence data from the field margins. A 2×2 contingency table for paired binary data was generated using PROC FREQ[17] by year and margin type for each species, and an exact two-sided test was used to test for an association between the two areas.

Data for each dominant weed species, combined across sampling dates within a year were used to test if margin type or presence in the field margin were predictors of presence of the weed in the crop field. Logistic regression using PROC GENMOD[17] tested the importance of the predictors: field, margin type, presence in the field margin and year. Reduced models were chosen for each species when appropriate.

Results

Total weed abundance

With the exception of margin type, differences were observed among main effects. Nevertheless, a number of interactions were evident among the main effects (Table 2). Interactions involving field and sampling date were present and were to be expected because of specific site and management histories of individual fields and due to the variation caused by annual and seasonal effects. The most important interaction was between margin type and distance in the crop field from the field edge.

Although a significant interaction between margin type and distance from field edge was observed; the cause was due to the abundance of a particular weed species [*U. platyphylla* (Munro ex C. Wright) R.D. Webster] in one field with an unmanaged margin across all five transects

Table 2. Sources of variance for total weed abundance in crop fields at FSRU of the CEFS, Goldsboro, NC.

Source	df	Mean square	*F* value	*P* value
Field	3	6.62	51.42	<0.001***
Margin type	1	0.078	0.60	0.44 NS
Field × margin	3	3.53	27.42	<0.001***
Distance	5	15.91	123.56	<0.001***
Field × distance	15	0.99	7.71	<0.001***
Margin × distance	5	0.55	4.27	0.001***
Date	3	35.40	274.77	<0.001***
Field × date	9	5.27	40.88	<0.001***
Margin × date	3	0.50	3.88	0.01**
Distance × date	15	1.14	8.84	<0.001***

**Significant at 0.01 level of probability.
***Significant at 0.001 level of probability.
NS, non-significant.

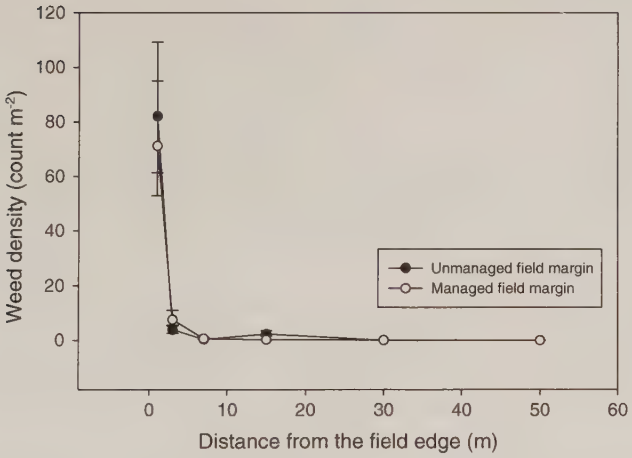

Figure 3. Density of total weed abundance by distance from the field edge for managed and unmanaged field margins across sampling dates ($P < 0.001$) at the FSRU of the CEFS, Goldsboro, NC, 2002–2003. Data were square root transformed for analysis and means were back-transformed for presentation.

at 15 m. In general, the total weed abundance for both managed and unmanaged margin types was observed to be greatest near the field edge and declined toward the center of the crop field (Fig. 3).

Field margin species richness and diversity

Over both years, approximately 65% of weeds were from the spring (May) sampling dates. In May 2002, 80 plant species were found in field margins; however, only 21 of those species appeared in a crop field as a weed, representing 26.3% of total species. The results were similar for 2003: of the 73 plant species found in the field margin, only 18, or 24.6%, were found as weedy species in a crop field at the spring sampling date. At least 74% of species in the field margin were not present in the crop fields surveyed. Across all sampling dates, a total of 105 plant

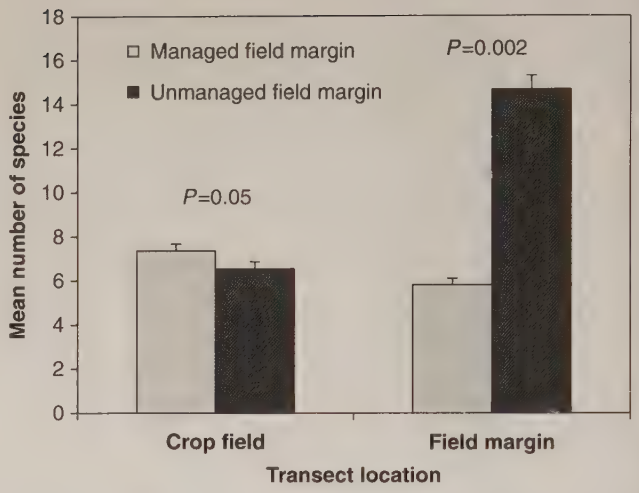

Figure 4. Species richness in crop fields and field margins for managed and unmanaged field margins at the FSRU of the Center for Environmental Farming Systems, Goldsboro, NC, 2002–2003.

species were identified in the field margins. Of these 105 species, 42 were found in the crop field representing 40% of total species sampled.

Species richness for weeds in the crop field along the two field margin types differed ($P = 0.05$). Crop fields (Fig. 4) adjoining managed field margins contained a greater mean number of weed species (7.4) than those adjoining unmanaged margins (6.6). However, the number of weed species found along field margins (Fig. 4) for unmanaged (14.7) field margins was more than double that for managed (5.8) field margins ($P = 0.002$).

Shannon's species diversity index returned similar results (data not shown). A significant distance by margin interaction ($P = 0.002$) result was detected, because diversity index means (H) were highest at the field edge (1.01), lowest in the field center (0.78) for the unmanaged field margin and similar (0.9 for both) at these two locations in the managed field margin.

Dominant species in the crop field

Nine dominant species were chosen for further individual analysis because these weeds tended to be the most common weeds at the CEFS. Of particular interest were *A. retroflexus* L. and *U. platyphylla* (Munro ex C. Wright) R.D. Webster, because these were most numerous and consistently present across all sampling dates. These nine dominant weeds constituted 84% of all weeds counted and of these nine, four species, *A. retroflexus* L., *U. platyphylla* (Munro ex C. Wright) R.D. Webster, *C. esculentus* L., *D. sanguinalis* L. and *M. verticilliata* L., comprised 80%.

Similar to the analysis for total weed abundance, numerous interactions between main effects were observed for the nine dominant weed species (Table 3). As previously mentioned for total weed abundance, the interactions involving field and sampling date were expected

Table 3. Sources of variance for dominant weed species in the crop fields at the FSRU of the CEFS, Goldsboro, NC.

	Main effects			
Weed[1]	**Field (F)**	**Margin (M)**	**Distance (D)**	**Date (Dte)**
AMARE	***	***	***	***
URPL2	***	*	***	***
CASOB	***	***	NS	**
CYPES	**	NS	**	***
SIDSP	***	NS	NS	***
IPOHSP	NS	NS	**	NS
MOLVE	***	NS	***	***
DIGSA	***	**	***	***
LAMAM	***	NS	***	**

	First-order interactions					
	F × M	**F × D**	**F × Dte**	**M × D**	**D × Dte**	**M × Dte**
AMARE	*	***	***	***	*	NS
URPL2	NS	***	***	***	***	NS
CASOB	***	***	***	***	NS	NS
CYPES	***	*	***	NS	NS	NS
SIDSP	NS	***	***	NS	NS	NS
IPOHSP	*	***	***	NS	NS	NS
MOLVE	***	***	***	*	*	***
DIGSA	***	*	***	***	***	NS
LAMAM	***	***	***	*	***	***

	Higher-order interactions				
	F × M × D	**F × M × Dte**	**F × D × Dte**	**M × D × Dte**	**F × M × D × Dte**
AMARE	***	NS	***	***	**
URPL2	***	NS	***	**	***
CASOB	***	**	NS	**	***
CYPES	***	NS	NS	*	***
SIDSP	*	NS	**	NS	*
IPOHSP	NS	*	NS	NS	NS
MOLVE	***	**	***	NS	***
DIGSA	***	**	***	***	***
LAMAM	***	*	***	**	***

[1] Bayer code: AMARE (*A. retroflexus* L.), URPL2 [*U. platyphylla* (Munro ex C. Wright) R.D. Webster], CYPES (*C. esculentus* L.), DIGSA [*D. sanguinalis* (L. Scop.)], IPOHSPP (*Ipomoea* spp.), LAMAM (*L. amplexicaule* L.), MOLVE (*M. verticilliata* L.), CASOB (*S. obtusifolia* L.) and SIDSP (*S. spinosa* L.).
NS, non-significant.
*Significant 0.05 level of probability.
**Significant 0.01 level of probability.
***Significant 0.001 level of probability.

due to the nature of specific field histories and seasonal fluctuations. The significant interaction of most interest was that involving margin type and distance from the field edge. Six of the nine dominant species had significant interactions between margin type and distance while three species, *C. esculentus*, *Ipomea* spp. and *S. spinosa* L., were non-significant for the aforementioned interaction.

Within the first 7 m of the field edge *A. retroflexus* L., *U. platyphylla* (Munro ex C. Wright) R.D. Webster, *D. sanguinalis* L. and *Mollugo verticillata* L. were the most dominant weeds (Fig. 5). These four species and *C. esculentus* (data not shown) had lowest numbers toward the field center for both margin types. The remaining four species had variable distributions throughout the fields. For example, *L. amplexicaule* L. and *S. obtusifolia* L. (results not shown) had more weeds toward the center than at field edges. There was no clear pattern among these weed species with regard to distributions by field margin types. *Amarathus retroflexus* L. (Fig. 5) associated with managed field margins tended to have significantly higher numbers near the field margins and in the field center than the same species associated with unmanaged field margins.

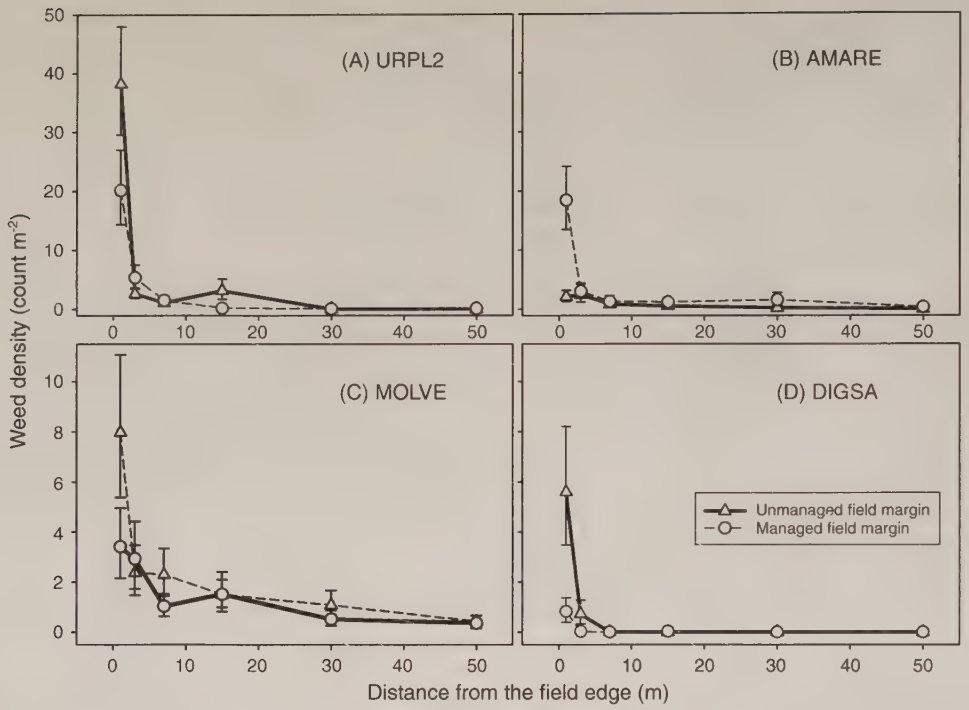

Figure 5. Mean densities of *U. platyphylla* (Munro ex C. Wright) R.D. Webster; *A. retroflexus* L.; *M. verticilliata* L.; and *D. sanguinalis* (L.; Scop.) by distance from the field edge for managed and unmanaged field margins at the FSRU of the CEFS, Goldsboro, NC, 2002–2003. Data were square root transformed for analysis and means were back-transformed for presentation.

However, *D. sanguinalis* (Fig. 5) numbers did not differ toward the field center for both margin types.

Association between weeds in the field margin and presence in the crop field

Because many of the species in the field margin were not found in the crop fields and because not all weedy species were found in the field margin, only a fraction of the total species generated 2×2 frequency tables with a majority of non-zero cells. They included: *U. platyphylla* (Munro ex C. Wright) R.D. Webster, *A. retroflexus* L., *S. spinosa* L., *C. esculentus* L. and *D. sanguinalis* L.

No associations were found for any of the tested species, except for *D. sanguinalis* (data not shown) for both managed and unmanaged margin types in 2003 ($P = 0.072$ and $P = 0.017$, respectively). Nevertheless, the association was not consistent over margin types, seasons or years.

Predictive power of presence in field margins

Logistic regression did not produce estimates or *P*-values for *M. verticillata* L., *Ipomea* spp., or *L. amplexicaule* L. due to large numbers of samples where these species were absent. For *U. platyphylla* (Munro ex C. Wright) R.D. Webster, *S. obtusifolia* L., *D. sanguinalis* L., *C. esculentus* L., *S. spinosa* L. and *A. retroflexus* L., field ($P = 0.05$–0.001) was the only significant predictor of the weed appearing in the crop field (data not shown).

Discussion

Weed species abundance, richness and diversity in crop fields

The pattern of total weed abundance encountered was consistent with previous European research[10,11] in which weed abundance was highest near the field edge and declined (or disappeared) as distance from the field margin increased. Abundance was similar between the two margin types with the exception of the 15 m distance from the field edge (Fig. 3). The obvious source of the interaction was a large, isolated population of *U. platyphylla* (Munro ex C. Wright) R.D. Webster about 15 m from the unmanaged margin in one field (Fig. 5). It was determined that crop rows approximately 15 m from the field edge may not have received herbicide applications in a previous year, resulting in an abundance of *U. platyphylla* (Munro ex C. Wright) R.D. Webster is this zone during the years of our study. This interaction between distance and margin type is most likely an anomaly.

Although the number of weed species found in crop fields associated with managed field margins was greater than for unmanaged field margins, it is not clear that this small difference is biologically relevant (Fig. 4). On the other hand, the fact that the number of plant species found in the margins of the unmanaged treatments was more than double that occurring in margins in the managed treatments seems logical, because a large proportion of these species (74%) did not occur as weeds in crop fields.

The significant interaction of field margin type with distance observed for Shannon's species diversity index was most likely associated with the presence of more non-weedy species occurring in the unmanaged field margins compared with the managed field margins. High levels of disturbance in the managed field margins could also have been a contributing factor.

Dominant weed species in the crop field

Although total weed abundance and its association with margin types and distances from the field edges are important considerations, weed species clearly differ in their response to such factors and thus it is perhaps more important to understand these weed-specific responses. This is particularly important with regard to the most competitive and difficult-to-control species. For example, with both margin types, *A. retroflexus* L. and *U. platyphylla* (Munro ex C. Wright) R.D. Webster had the highest number of weeds at the crop edge within the first 7 m and the lowest numbers of weeds toward the center of the field (Fig. 5). Because these two weed species had the highest total abundance (50%) of all the dominant species, these were likely the cause of the overall total weed abundance trend. Other species were lower in total abundance and had varying distributions across the field (data not shown).

Field margin species richness

Results from this experiment are consistent with earlier observations[10] in which 20–40% of field margin species were weedy species that commonly occurred in cultivated fields and at least 60% of plant species were found in the field margin only (i.e., not found in the cultivated field). Therefore, a majority of the plant species found in the field margin would not be considered weedy or threats to crop performance. Moreover, only a few species of weeds out of the entire assemblage were most problematic to crop production and these dominant species tended to be present regardless of margin type (Fig. 5).

Unmanaged field margins could provide higher conservation and habitat potential than managed field margins. Joenje and Kleijn[19] postulated that, for a newly established field margin, species richness would be high initially, followed by a period of moderate diversity and then an increase in species richness over time. Kleijn[5] maintains that high plant species diversity is directly related to high insect diversity and low herbivore/predator ratios and that these areas can act as ecosystem regulators of insect pest problems and perhaps reduce the need for agrochemicals in the crop field. Therefore, as field margins continue to increase in plant species richness, conservation and habitat potential are expected to increase.

Association between weeds in the field margin and presence in the crop field

The association of field margins with *D. sanguinalis* was not predictive, and the direction of the relationship was not consistent over margin types or over sampling years. Wilcox et al.[15] found a non-linear relationship between crop yield and weed biomass with respect to distance from the field edge, and suggested that weed competition alone could not be responsible for reduced yield in the crop edge because when yield was adjusted for weed biomass, there was still evidence of a distance effect. This suggests that other factors such as soil compaction, non-uniform application of herbicide and fertilizer could help explain reduced crop performance. They also suggest that high weed biomass in these areas may be a result of poor crop performance. Although it is possible that some individual plants of weed species in our study originated from the field margin, any perceived threat posed by unmanaged margins (compared with managed margins) appears to be unfounded.

Predictive power of presence in field margins

The field and year were effective predictors only for *D. sanguinalis* L. ($P = 0.001$ and 0.01, respectively) and *C. esculentus* L. ($P = 0.05$ and 0.03, respectively) appearing as weeds in the crop field. Our analysis indicated field as an appropriate predictor of the weed occurring in the crop field for most weed species. This is understandable considering that individual field histories and knowledge of past weed populations are very important when predicting what weeds will occur the following year and determining which management tactics to use. For most species, the factors of greatest interest to this research, presence in the field margin and margin type, were not associated with presence of the weed in the crop field.

Blumenthal and Jordan[20] suggested that because the number of weeds considered most competitive with crops is so limited, it may be possible to reduce disturbance of natural habitats without negative consequences to the adjacent crop.

We realize that different field histories and data from a single location limit broad inferences of our data. Nevertheless, results for the fields in our study support the hypothesis that, in general, more weeds appear near the crop edge than field center, but probably not because they are present in the field margin. We argue that this occurrence is more likely because crop edges tend to be managed differently than the rest of the crop field. As fields are prepared for planting, different levels of cultivation, herbicide and fertilizer application are found at the outer edges of the field versus within the field[2]. This research supports the hypothesis that natural and semi-natural habitats in the farm landscape are not necessarily associated with weed contamination of adjacent crop fields, suggesting that farms should be managed on landscape as well as field levels.

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Essential multiple functions of farms in rural communities and landscapes

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Abstract

As farms are consolidated into larger operations and small farms close down for economic reasons, rural areas lose ecological, social and economic functions related to farming. Biodiversity and scenic, open-vista landscapes are lost as fields are left unmanaged. Social and economic benefits such as local job opportunities and meeting places disappear. Four Swedish rural communities were examined to increase our understanding of the functions that a diverse agriculture provides and which of these are lost as farms cease operation and overall rural social capital is depleted. Workshops and interviews with village action groups and with farmers were carried out. Both groups identified key functions from farming that are important to the rural community, such as production of food and fiber, businesses and jobs, human services, local security, ecosystem services such as nutrient cycling and biodiversity, and functions pertaining to quality of life. Several ways in which village action groups can support agriculture were identified that current industrial agriculture and even agri-environmental schemes fail to achieve. These include organizing local meeting places, encouraging local processing and consumption and supporting farmers in their work. We conclude that agriculture and village action groups match well in community development and that policies supporting this match would be useful.

Key words: multifunctional agriculture, ecosystem services, village action groups, rural development, Sweden

Introduction

Two simultaneous trends in European agriculture currently affect the development of farms: intensification into larger farms in plain areas and small farms in marginal areas going out of production. Intensification has been achieved through increased specialization, mechanization and industrialization of production. To support this transformation, the use of external inputs such as synthetic fertilizers and pesticides has increased. Intensification has increased yields substantially since the 1950s, but industrial farming has also had negative impacts on landscape heterogeneity, wild and on-farm biodiversity and local communities (e.g.[1–4]). In other areas, concurrently, ecosystems and communities are negatively affected by the loss of farm production, i.e., increased number of farms that reduce their level of activity to the degree that fields are left unmanaged, animals disappear from the landscape and ultimately farms are closed down as production units[5]. In Sweden, areas of farm loss can be found in all areas dominated by forests. These regions used to be characterized by dairy production. However, since the 1980s the number of dairy farms in Sweden has decreased by 80%, the number of dairy cows has decreased by 44%, but the production of milk has only seen a 10% reduction[6,7]. Due to changes in technology and animal material, each cow now produces 40% more milk. During the same time period, the average herd size increased from 15 to 52 cows. This trend can be found in all types of agricultural production in Sweden. While small to middle-sized farms in forest-dominated areas either reduce farming activities or close down, farms in lowland areas suitable for arable farming become fewer and larger[6]. Both these processes influence wild biodiversity in mainly negative ways. Since semi-natural grasslands are one of the most biodiversity rich habitats, forestation of these areas decreases biodiversity[8]. Similarly, farms with large herds of dairy cows are not able to use semi-natural grasslands properly since some of them will be situated too far away

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from the farm center. Instead, cows are fed with imported feed, needed to keep up the high production of milk.

In Sweden, as in other countries in the European Union (EU), agriculture is supported by different subsidies, including direct payments, agri-environmental schemes and other payments in the rural development program. Despite this support that Swedish farmers have been eligible to receive since accession into the EU in 1995, farms continue to close down due to low economic viability in areas dominated by forests.

It is widely accepted that agricultural production activities in crops and livestock bring with them a number of functions that are beneficial for rural communities and society at large[9]. For example, agriculture plays an important role for rural tourism because the diversity of natural habitats and the scenic beauty of rural landscapes are closely related to the type and intensity of land use[10]. Large-scale cereal farming is less suited for the management of a mosaic landscape, where fields are small and scattered, or where large forests separate the open areas of agricultural land[11]. It is in these mosaic landscapes with multiple ecotones that most biodiversity can be found[8,12]. In addition, environmental sustainability also benefits rural communities[2,13]. For example, sustainable farming methods tend to require more locally produced inputs and services, which increases local trade and support businesses within communities[13]. Thus, as farms become more extensive or close down, a number of functions other than food production are also lost.

These several trends, together with the depopulation of rural areas, loss of human services and infrastructure, such as schools, shops, medical facilities and post offices, have given many people in rural areas a general feeling of being left out in the development of mainstream society. A combination of factors has induced groups of rural residents to take action and form village action groups in Sweden and other countries[14]. These groups consist of people who want to develop their local communities with projects that range from saving the local school to inspiring farmers to produce and sell products locally. Many of these groups in Sweden are concerned about the loss of farms, because they see a direct link between the development of agriculture and their local communities.

The objectives of the research presented in this paper were to explore what functions farms have for the villages they are situated in, as well as how village action groups can support farms in sustaining these functions. Using cases from four rural areas in Sweden, we explore the research questions of how the loss of active farm production affects the rural communities in which the farms are located and what rural inhabitants do to counter this trend. We do this by taking a closer look at the functions farms and farmers provide to rural communities and landscapes in areas where farms and farmers are decreasing in numbers. Better understanding of rural change can contribute to improved design of education and other intervention programs that will lead to improved quality of rural life.

Multiple Functions of Agriculture and Rural Development

Agricultural systems are situated within social, economic and political environments that influence how they operate; globalization and low margins in conventional agriculture are among the most important factors that appear to require increased scale and efficiency[15]. As a result, the relative economic importance of agriculture in many countries is on the decline and the rural sector is no longer the monopoly of farmers[10]. Indeed, in many rural regions, agriculture is no longer neither the main user of labor nor the main source of regional income[16]. Intensification in plain areas and loss of small farm agriculture in forest-dominated areas both result in transformed landscapes[16]. The countryside is also economically and socially transformed by resource flows arising from amenity-based consumption[17].

However, it is widely recognized that European agriculture has the capacity to produce a broad range of so-called public goods[10]. Much of the beauty and biodiversity of landscapes in Europe depend on the continuation of active farming[18] where human interaction is indispensable[11]. For example, acceptable economic returns from agriculture with animal husbandry are vital for the continuing management of the biodiversity-rich, semi-natural grasslands[11].

More than any other rural activity, farming has the capacity to play a vital role in rural development[19]. The current neo-conventional agro-industrial logic, which defines rural areas as intensive production space, has driven many farmers into a dead end in terms of economic return and social life, as well as caused environmental loading[20]. Yet there are other models of rural development where farming can have a central role in achieving rural sustainability goals (cf.[20]). This central role for enhancing sustainable rural development can be realized if farms are defined as potential multifunctional rural enterprises serving a variety of markets[21]. From a contemporary perspective, all farms were multifunctional in their organization a century ago, because they were designed to serve a multitude of purposes for the farm family and the rural community[22].

Multifunctionality describes farming systems that meet multiple needs of the family as well as providing ecosystem services[22]. The concept provides perspective as a tool for focusing not only on the negative side effects of farming, which are often emphasized in the sustainability debate, but also on the positive effects that we want farming to have for rural areas and society at large[9,22]. Multifunctionality suggests that agriculture can deliver valued functions that cannot be produced by other economic sectors[18]. Among the positive side effects of farming are aesthetic values, recreation, water accumulation and storage, nutrient cycling and fixation, wildlife habitat, storm protection and flood control. In other words, agriculture produces and supports a number of vital ecosystem services on which humanity depends (cf.[23–26]). Ecosystem services are the

benefits people obtain from ecosystems[25]. There are research initiatives to recognize the value of such ecosystem services, which are not normally rewarded by the current economic system[27].

Wilson[28] argues that expressions of multifunctionality are most important at the farm level because they lead to tangible effects in the farmed landscape, catalyze crucial farm–community interactions and improve the quality of local production. According to Wilson[28], strong and viable multifunctional farms are both embedded in, and also shape, the local and regional landscapes and contribute to environmental sustainability. In addition, multifunctional farms display low production intensity and put less pressure on scarce natural resources[26]. However, farms do not necessarily stay at the same level of multifunctionality. When changes take place such as fewer or more employees, changes at the field and farm levels, or intensifying pressures due to external circumstances, farmers need to adapt; this may influence the multifunctionality of the farm[27]. Thus, the complexity of multiple functions is dynamic and not all farms have or maintain the same level of diversity of structure and function over time.

Multifunctionality also implies legitimizing non-market goods and services in planning and policy[29], and designing strategies that will lead to greater economic recognition of the importance of multiple services. The concept of multifunctionality has thus been used in various international negotiations to legitimize public support to agriculture[30]. Since the European Commission committed to multifunctionality in 1996[31], multifunctional agriculture has been part of the European model of agriculture[32]. As a result, some actors in the US agricultural industry have viewed multifunctionality as a protectionist measure to continue EU subsidies under the guise of environmental protection[18]. However, the normative view of multifunctionality, which is assumed in this paper, suggests that the concept should not be seen as a term appropriated by European policy-makers to defend farm subsidies, but as a process for explaining what is happening at the farm level[33].

Swedish Context

The rural development dynamic has its roots among the bottom-up initiatives associated with the empowerment of 'peripheral' rural communities[21]. The village action movement in Sweden arose, as in some other Scandinavian and European countries, as a response to the rapidly changing economic and social circumstances in rural areas[14]. The main effects of change include: increasing urbanization and centralization, decline of agriculture, decline of rural services, depopulation of rural areas, regional inequalities, isolation of rural communities and the need for a stronger political voice in non-urban communities[34]. Successful rural development often relies on the positive interactions among and sustained commitment of small groups of individuals[35]. The first village action groups were formed in Sweden in the 1970s. In 1989, the existing village action groups joined together under the umbrella of the Swedish Popular Movements Council for Rural Development. There are currently some 4700 village action groups in Sweden[36]. There is no clear definition of village action groups, more than that these groups work to promote local development. They should be open to all and work publicly; they are appointed locally and arrive at decisions in a democratic way. Groups can look very differently. For example, while some focus on developing local tourist attractions, others may find sustaining cultural heritage or a specific landscape type more important. Some groups manage to attract funding for their activities while other groups do not. In short, groups are formed by committed individuals and focus on the activities found important by those active in the group. Thus, in some groups, local farmers are members, while in other contexts farmers find it more useful to take part in local farmer association groups. However, all inhabitants in a village are considered members of the local village action group. Groups operate in a district—the village or the parish—as defined by the inhabitants themselves[36]. In the village action groups referred to in this paper, some of the interviewed farmers were active members of the groups. In most cases, however, farmers knew about the village action group but did not actively participate.

Farmers and village action groups are entitled to apply for subsidies from the EU. Individual farmers can apply for direct payments, such as payment per hectare of arable land or pastures, and for environmental supports, such as payments for delivering services or functions that are wanted from society. Furthermore, new farmers can apply for start-up grants and all farmers can apply for investment grants. Farmers and local people can together apply for project support, for example, projects that support several stakeholders such as a community kitchen for processing of local products into locally branded products or a cooperative sales outlet. However, the largest part of the EU subsidy budget is allocated first to direct payments and second to agri-environmental schemes. These support programs enhance the economic viability and encourage multifunctional activities in communities that are embedded in rural landscapes.

Methods

Four rural areas in Sweden (Table 1) were selected from a larger rural 'Sustainable Villages' development project that included 14 pilot areas. The project 'Sustainable Villages' was carried out by the Village Action Movement in Sweden 2003–2006 and was funded by the Swedish Rural Development Program. Each participating village action group obtained funds for a project leader. The aim was to show a diversity of sustainable rural development in less-favored areas in relation to natural resource management. The study areas were chosen in places where a village action group was working actively with issues of farming. A geographic spread was also a goal. The villages are

Table 1. Description of the villages in the study.

	Village 1	Village 2	Village 3	Village 4
Number of inhabitants (approximately)	5000	150	335	900
Number of active farms	300	5	10–20	15
Number of full-time farms	11	2	–	4
Main farm production	Vegetables, berries, milk, meat, eggs, cereals, potatoes	Milk, meat, cereals	Meat	Milk, meat, cereals
Landscape type	Mixed farming and forested	Mixed farming and forested	Dominated by forest	Dominated by forest
Special feature of the village	Summer tourism	Cooperation on nutrient cycling between farmer and inhabitants	State company owns 95% of the forest	Some farmers have large (100–400 ha) forest holdings

spread out in the middle and south of Sweden. The aim was not to represent all of Sweden, but rather to illustrate the potential emergence of a rich picture of multifunctionality in rural Sweden. In each area, the active members of the village action groups consisted of 5–10 people. In most cases, these were middle-aged or retired people. There was a mix of people who had lived in the villages all their lives and people who had settled there. In all groups, at least one farmer was active. In addition, local shop owners, retired extension agents, foresters and people with a special interest in, e.g., cultural heritage, tourism or just a commitment for the village were represented. Despite the limited number of active members, a broad range of competencies was represented as well as a historical depth concerning the village. However, the young generation was missing, which the groups were aware of.

In all study areas most people commuted to nearby towns to work. In addition, the economic viability of agriculture was low in most cases. Many of the farmers running small and medium-sized units did not particularly aim at maximizing yields, but were more interested in finding time- and cost-saving solutions for the farming system which would make it possible for them to continue farming (cf.[11]). The farms in the four areas were diverse, both in their production and size. The typical farm had between 10 and 30 ha arable land. Vegetable and cereal production, as well as egg, meat and milk production, could be found (Table 1). However, the main trend was that farms in the areas had gone from dairy farming to suckler cow rearing and from full-time farming to part-time farming. The farmers who were interviewed in this study were also diverse (Table 2). In addition to differences in size, production and how many people the farm could support financially, both female and male farmers were represented, as well as farmers in their early 20s up to late 60s. The majority of the farmers were born on the farm or in the same area. Only two had settled in the area as grown-ups.

This was an explorative study. The aim was to better understand what functions local agriculture had for the villages, and how village action groups supported the viability of agriculture. These issues were explored through workshops with village action groups and interviews with farmers. A one-day workshop with active members of the local village action group was carried out using participatory tools[37] where we focused on the economic, social and ecological links between local farms and the rural community. The purpose was for the researchers to get to know the village, start discussing the functions of agriculture for the village, as well as the activities of the village action group. Participants were asked to draw a map of their village. In doing this, we discussed the borders of the village, and what important features the village had, as well as the activities of the village action group. Further, workshop participants were asked to discuss influences on the village from the outside world. Another exercise was to brainstorm all functions agriculture had in the village. Finally, the village action group members were asked to draw up a joint vision for the village 20 years from now. In total, 26 members of village action groups participated in the four workshops. The sample of interviewed farmers was purposive[38]. In order to find farmers to interview, village action groups were asked to recommend farmers. In village 1, with a large number of active farms, we got a list of full-time and 'almost full-time' farmers from one knowledgeable person in the village action group. From this list, we then selected as diverse farms as possible concerning age, gender, production, size and location. In the other villages we got comprehensive lists from the village action groups of active farms in the area and selected farmers to approach. Four to seven farmers were interviewed in each community, using semi-structured interviews[38]. In total, 17 farms were visited (Table 2). The farmers were asked about their role in their rural area, how this role had changed over the years and what they anticipated their role would be in the future. They were also asked about the possibilities for further developing their farms and the obstacles they saw for this development. The aim of interviews and workshops was thus to create a rich picture of current and possible future functions farms could have for the benefit of the rural community. All interviews were taped and transcribed. The narrative data collected were thematically analyzed on their content, focusing on the functions of the farm, the

Table 2. Description of the farms in the study.

Farm in village	Land	Animals	Production	Employment in agriculture[1]
1	29 ha arable land 6 ha pasture, 36 ha forest	36 cows 10 laying hens	Milk	100%
1	85 ha arable land 17 ha pasture, 80 ha forest	64 cows	Milk	100%
1	140 ha pastures (leased land)	200 ewes	Mutton	100%
1	430 ha arable land 60 ha pasture	600 beef animals	Organic beef	500%
1	180 ha arable land	3500 laying hens	Cereals, eggs, maize	200%
1	52 ha arable land 50 ha forest		Cereals, potatoes, firewood	100%
2	43 ha arable land 26 ha pasture, 30 ha forest	18 cows 25 ewes hens, ducks	Organic milk	200%
2	70 ha arable land 40 ha pasture, ≈ 10 ha forest	35 cows	Milk	200%
3	46 ha arable land 40 ha pasture, 77 ha forest	30 cows and calves	Beef, hay	100%
3	15 ha arable land 5 ha pasture, 135 ha forest	20 ewes 7 cows and calves	Mutton and beef	25%
3	30 ha arable land 4 ha pasture, 66 ha forest	35 cows and calves	Beef	25%
3	12 ha arable land 18 ha pasture, 10 ha forest	11 ewes 4 cows and calves	Mutton and beef	25%
3	6 ha arable land 2 ha pasture, 25 ha forest	3 cows and calves		0%
4	42 ha arable land 16 ha pasture, 185 ha forest	20 cows, 1 horse	Organic milk	200%
4	50 ha arable land 275 ha forest		Cereals	20%
4	34 ha arable land 2 ha pasture, 300 ha forest		Cereals, hay	20%
4	25 ha arable land (leased to other farmer), 300 ha forest	3 horses	Bed & box	100%

[1] One full-time employed person = 100%.

contribution of the farm to rural development and how the village action group could support the farmers[39]. Data on the economic situation of the farm were collected as well as data on production and material flows. All areas were visited twice. The second time, the researchers presented preliminary results from the workshop and interviews and invited farmers, village action groups and other interested local citizens to comment and help adjust the findings. In total, these seminars attracted 47 participants. The process was designed to assess the current and potential future multifunctionality of each area. The themes that emerged in the workshops and interviews are summarized in Table 3.

Results

The farmers and the participants in the village action groups mentioned similar services and functions that the farms and agriculture delivered to the local community, even if they were partly described in different terms by farmers and village action groups (Table 3). Since the village action groups considered the sustaining of farming in the villages to be important, they organized activities in order to support local farms in different ways (Table 3). The services that were brought up were ecological, economic and social; some are paid and some are not paid.

Maintain open landscapes

Both farmers and village action groups considered maintaining an open agricultural landscape as the most important function of local farms. All four villages were situated in forested areas where the agricultural fields were scarce and the forest dominated. Forests were important for income and livelihoods but there was also a threat from the forest 'taking over' the landscape as farms were closed down or used less actively. A farmer who managed several farms in one of the villages expressed:

> Much of the land I manage would be forested. Four of the farms I use would be forest unless I managed them. All

Table 3. Functions provided to the local community by farmers according to farmers and village action groups, and actions taken by village action groups to support local farms.

Functions provided to the local community by farmers	What village action groups did to support local farms
Maintain open landscapes	Local small-scale dairy; joint management of hay meadow; joint cow shed
Food and energy production	Processing and marketing of local products to support local consumption (organize market days, produce apple juice and joint potato cultivation)
Support local business and tourism	Horse trail; breakfast meetings for entrepreneurs, study tours, buy empty buildings
Provide services (digging, road maintenance, etc.)	Land provision for local small-scale production, study tours
Create job opportunities	Create interest among children for food production (school gardening)
Provide basis for nutrient cycling	Provide urine and sludge
Security in the community	
Provide meeting places	Provide more meeting places (buy and use empty buildings)
Possess local ecological knowledge	Promote knowledge exchange (breakfast meetings for entrepreneurs, create regional sheep-breeding center)
	Contact with authorities and the municipality

> places would be planted [with trees], that's for sure. So in that way ... in order for the landscape to be open, maybe I'm needed.

Farmers mentioned the maintenance of an open landscape as important for two reasons. First, they acknowledged that other rural residents enjoyed living in an open landscape. Second, they themselves appreciated an open mosaic landscape. The open landscape represented a managed landscape conveying the works of many generations of farmers, i.e., the open landscape was open in both a spatial and a temporal sense. Farmers performed traditional agricultural work and a farm may have been active for generations. In this sense, farms represented and maintained cultural heritage. Further, some farmers had historically valuable remnants in fields and forests, such as stonewalls, old buildings, ruins or graves from earlier centuries or millennia. This cultural heritage was visible due to the management system of farmers. For example:

> ...and there's a stonewall ... and these old house ruins and all and barns out in the forest, where the fields used to be. And you can see them because I use the forest for grazing.

The open landscape was also seen as a prerequisite for other activities in the area, such as tourism and recreation. The open agricultural landscape was suitable for walks, bicycle trips and bird watching. The managed forest was ideal for berry and mushroom picking, hunting and also for bird watching. A quality in the open landscape that was mentioned in the villages was the prevalence of grazing animals. Both farmers and village action group members reasoned that people feel better when they see grazing animals and that these were a natural part of the agricultural landscape. Grazing was both a social and an ecological service to the villages. Two farmers explained:

> And then my cows graze the neighbor village, and so on. And at some more neighbors around here. ... There aren't many who have animals around here, they pull at you in spring. They all want animals.

> Well, I think it would be boring if the animals disappeared, because animals belong in the country side, I think ... it is fun to see, especially during summers. When they graze outdoors, it's sort of, it belongs here.

The open landscape, or rather the threat of losing the open landscape, was a major driver for the work in the village action groups in all villages. An important aim of the groups was to make sure that the remaining farms in the area were viable farm operations that managed and developed the open landscape. In one of the villages (4) where cattle and dairy cows were quickly disappearing from the landscape and many people were interested in local food products, the village action group bought a small mobile milk processing facility and put it in the village center. In this way, small-scale milk producers could rent the facility and process their milk into cheese, which they sold locally. In this village action group, a part-time farmer was a leading actor, and so many activities of the group concerned farming activities. A discussion in this village considered whether the village action group should support the building of a cooperatively owned suckler cow shed. While buildings for grazing cows for meat production were expensive for each individual farmer, a common cowshed could decrease costs, increase efficiency and reclaim some of the previously grazed land in the village. Another village action group (2) managed a hay meadow together with a farmer. This helped the maintenance of a species-rich meadow, but was also a social occasion and an opportunity to revitalize and maintain knowledge on farming for the rural residents. This village action group was highly influenced by one of the participating farming families, which offered their land and knowledge to a number of activities for the benefit of the village.

Food and energy production

The production of food created the open landscapes. Production of food and fibers provided an income, albeit small in many cases, for all farms in the study. However, the production and processing of food on the one hand, and the consumption of food on the other, were mainly occurring at different scales. For example, animals were transported and slaughtered far away from the farm and later sold in stores as anonymous meat cuts. The majority of the farms with animals sold their products to large-scale processors, and in these cases farm products were not a direct contribution to the food consumption in the village but to the Swedish food system overall. This may be the reason why only one farmer mentioned food production as a service to the village. This farmer sold products directly to consumers in the village. However, six out of 17 interviewed farmers, and in all four villages, sold products directly to consumers at their farm or through deliveries. These products included eggs, meat, milk and vegetables. In most cases, these sales provided an important income source for the farmers. We can only speculate on why these farmers did not mention food production as a service to their communities. One reason may be that food production is so self-evident for farmers that they 'forget' about it. Another reason may be the way the interviews were laid out to focus on additional services and functions to the local community.

Three of the farms were certified organic. Two sold milk and milk products (such as cheese and cheese cake) and one farm produced beef (Table 2). In the case of village 1, the farms that sold directly to local consumers did not experience that consumers demanded organic quality. These consumers were happy to pay for the added value of local production. For the farms in village 3, organic certification was not an option since they were economically weak and produced beef (mainly) to sustain landscape values. For an organic certification to pay, production and farms would have had to be larger. In village 4, farmers with cereal production lived from the forest and farmed arable land in order to maintain the open landscape. Thus, their production was too limited to pay for organic certification. Only in the case of village 2, where one of the farmer couples was the hub of all activities, organic certification was an issue. In this village, nutrient cycling, organic production and low-energy food production were hot issues, supported by committed villagers.

People in the village action groups seemed keen on developing projects that allowed them to 'taste' or 'use' the landscape, e.g., local dairy products, meat and vegetables. Local products that were unique were also considered important to attract tourists. One village action group (4) collected leftover apples each autumn and made local apple juice that was sold in the village supermarket. Another group (3) organized market days to attract people to the village and to provide local farmers with an opportunity to show off their products. This group was a mix of people who were interested in cultural heritage of the area and people who were working for re-population of the area. Markets days with an old-fashioned touch satisfied both groups. A third group (2) organized joint potato cultivation on the land of the farming family that was the hub for all activities of this group. All village action groups discussed the possibilities to decrease the use of fossil fuels in the local community by converting agricultural products to renewable energy. Another reason village action groups focused on local food production was the awareness that fossil fuels will become more expensive in the future, making long-distance transport of food impossible. For the village action groups, local food production and processing was a way to increase robustness of their communities.

Businesses, services and jobs

An open and living landscape attracted both local dwellers and tourists. The farms and farming activities were perceived to bring life to the landscape. The farmed, mosaic landscape attracted tourists, but the villages needed additional activities and facilities to deepen this attraction. The activities they mentioned were horse or walking trails, bed and breakfast, fishing and selling of local foods with added value. Farmers and the village actions groups discussed the possibilities of processing farm products and selling locally branded items that showed the added value of that specific product, e.g., the production of local cheese (4). In that case local milk was needed, and thus grasslands in the community were grazed and biodiversity enhanced. In addition, local resources such as labor and know-how were also required to run the local dairy.

Farmers also mentioned services they provided, such as pulling cars out of ditches, lending machines to other residents or repairing machines of others, as contributions they made to their villages. Other related activities were rental of summerhouses, digging works or rental of storage buildings. Since farmers normally had a number of machines few other rural residents had, this equipment could also be used for purposes other than farm work, which had both economic and social value for the area and the farmers themselves. One farmer expressed it in this way:

> And different kinds of machines that I have; tractors, diggers and all, and there could be someone driving into the ditch and needs a favor, it is there.

Most farms within the villages were small and were thus family farms without employees outside the family. However, indirectly their production created jobs, e.g., in food processing and tourism, and one larger farm with grazing animals employed a handful of people (Table 2). In addition, farmers mentioned the effect their needs for repair and purchases had for local businesses.

All village action groups saw the need to strengthen farming as an entrepreneurial activity. One group (1) organized breakfast meetings for all local entrepreneurs to provide knowledge exchange and networking. The same

group organized study tours for local farmers to businesses and farms with innovations such as renewable energy production or on-farm food processing. This village action group consisted of active farmers and retired rural residents with an interest of local development. Thus, many of the activities this group developed were firmly grounded in the farming community. Another group (4) tried to increase interest among schoolchildren for agriculture through a school vegetable garden.

Provide basis for nutrient cycling

One farmer pointed out that her farm was a base for local nutrient cycling. This farm and the village action group (2) had an explicit aim of recycling. The farming family collected human urine and sludge from neighboring residents. The farmer stated:

> For the recycling to function you need a farm, and we provided that. Our role is to provide that space.

In all villages the local nutrient cycle was mentioned as an important issue. This included local production, local consumption and local return of compost and sludge. The last part was the hardest to realize and it was found only on the above-mentioned farm in one of the villages.

Security in the community

A farm couple argued that the fact that they were at home during daytime was a service they provided for the village. Since most other residents were in town working or in school, only farmers were in the village to provide help if something happened. In their words:

> That there is someone here in the middle of the day. So, I mean, otherwise people go to town to work. It is totally deserted and then the old people, if they fall down and can't get up, we have to go and get them up. Yes, it is a security, that there are people around.

These farmers also mentioned the fact that they were the only ones that had an electricity generator, which was important for security when there was a power failure. All village action groups also mentioned the farms as a stable and secure backbone in the community. The fact that someone was at home during the day but also because of the know-how farmers had. Their ability to perform as a 'jack-of-all-trades' and the machinery they possessed created this local security.

Provide meeting places

In two of the interviews farmers said that their farms were meeting places. They mentioned different reasons for this claim. One was that there was a farm shop and rural residents came by to buy food, or a machinery repair service that attracted customers. Examples from the farms in the study included farm gate selling of eggs, milk, handicrafts, firewood, potatoes, hay, manure and meat, as well as rental of machines, child care and study visits. If the farmer was a sociable person, the farm became a meeting place for that reason. Farm buildings, machines and fields were used for social purposes, e.g., sports activities were undertaken in newly mowed fields. One farmer offered land for members of the village action group to grow potatoes, which increased the possibilities for people to come together, meet the farmer and share each other's concerns.

The village action groups mentioned the lack of meeting places as a constraint for community development. Therefore, they had created different kinds of meeting places or incentives to meet. As mentioned before, one village action group (1) organized breakfast meetings with farmers and other entrepreneurs in order to create regular opportunities for exchange of experiences and information. Two of the village action groups (3 and 4) had purchased empty buildings from the municipality and now used them for meetings and social events. This also benefited the farmers, since they could take part in the social life of the village.

Possess local ecological knowledge

The village action groups valued the local and ecological knowledge that farmers held. Farmers were knowledgeable about the area and its history. This gave people a context, which in turn created feelings of community and a sense of place[40]. Farming includes work in and with nature and thus farmers had an awareness and knowledge of local agro-ecosystems. This knowledge was often focused on larger landscape and ecosystem scales and less on species knowledge.

One village action group (3) planned to open a regional sheep-breeding center, inviting farmers to share and exchange their knowledge for the benefit of sheep farming in the area. A major concern for this group was to keep viability of farming in the area and to attract new entrepreneurs to the area. Another group (1) made sure farmers' knowledge was spread during the program of their breakfast meetings mentioned earlier. Some farmers received study visits from schools or other interested groups. This provided income as well as knowledge exchange.

Contact with authorities and the municipality

Farmers and village action groups mentioned the administrative workload as a problem for the development of local products and the establishment of new farms or production units. Some of the farmers felt that the contact with authorities was an obstacle for development, and they did not consider public services or extension agents to be of any significant help. According to some of the farmers, conventional extension agencies emphasized increase of scale as the sole alternative for development. For farmers who wanted to develop in other ways, e.g., diversify or stay small, this was not a viable option. One way village action groups (1, 3 and 4) wanted to support farmers was to be a link to authorities. In the villages there were people working with administration, with authorities or at the

municipality level, and thus it was possible to use their knowledge to help farmers or local companies. For example, in order to provide the mobile dairy in one of the villages, more than a year of applications, controls and adjustments were needed before the county administrative board approved it. The village action group (4) did most of this work.

Important reasons village action groups were formed were because the villagers had to fight to save the local school, the fire station or local grocery store. In all cases, the village action groups had managed to become a voice the municipality listened to. The village action groups did not win all their fights, but often they created something else instead. In one case the village action group (3) took over the management of the old school building after the municipality had closed it. The building was used as a community center, offering a kindergarten, meeting place and seminar rooms. In another case the village action group (4) took over the fire station the municipality closed and now managed it with volunteers. Thus, village action groups created conditions for communities to function, benefiting farmers as well as all other rural residents.

Discussion

The focus in this study was on functions from agriculture and what farmers and their managed landscapes provided that were relevant for the local community. These include functions in the social, economic and ecological realms. Social functions are directly beneficial for the local community (meeting places, scenic landscapes and security) and can also enhance the well-being of the farmer. Economic functions are characterized by the fact that the farmer can gain an income from them and that they are beneficial for the rural community as job opportunities or the availability of local foods with identity and added value. Ecological functions are important for the sustainability of agro-ecosystems, and can be important preconditions for recreation, tourism or health.

Functions from agriculture can emerge in three different ways. First, the farmer and farming family produce goods or services depending on their interests, commitments and personalities. For example, a farmer can be more or less inclined to cooperate with others or take more or less interest in natural values and cultural heritage. Second, the farm and farmer give services to the rural community because of farming as an activity and how it maintains the rural character. This includes the production of a certain landscape that would not be there otherwise. Another service is that a person is at home most times of the day and can help if something happens or if there is an emergency. And third, the farm as a place also gives services to the local community, such as being a meeting place or offering the possibility to play softball on a farm field.

Of all functions farming has for the villages, only some of them are remunerated. Many citizens do things for free, and so do farmers; however, the relation between paid and unpaid activities has to be proportionate. Thus, if farmers experience too low an income from farming activities, there is a risk that they will decide to discontinue farming, and thus villages lose all functions associated with these farms. Farmers can only be paid for services for which there is a market, such as agricultural products, machinery services, tourism and ecological functions that are paid through agri-environmental schemes. Most functions that are unpaid are related to social or ecological services (see Table 3). Only if the farmer is involved in tourism, he/she can be paid for the landscape and recreation values that are created through farming.

However, unpaid functions of farms do not have to be paid in order for them to benefit farmers directly. For example, civic participation can benefit farmers by helping them to build social capital, which enhances farmers' integration in the community, increasing well-being and economic opportunities (cf.[13]). Nurturing social functions such as meeting places, education and security is a satisfaction and can increase quality in life (cf.[41]). In addition, even if the farmer is not directly paid for all services to the village, these services can be compensated in other ways. For instance, managing biodiversity and soils can bring higher yields and fewer pests[42]. Thus, unpaid functions can be created if they are needed from the farmers' point of view, that is, if there are positive feedbacks such as work satisfaction, increased soil fertility or beautiful surroundings. At the same time, a farmer does not have the capacity to only create unpaid functions, despite that they may be important for family well-being, farm production and the welfare of the community. As with all rural residents, farmers need an income. In summary, unpaid functions need to be created and sustained via paid functions whenever possible. If there is an incentive for the farmer, there is a potential for the function to be created in the future as well. For example, agri-environmental schemes pay farmers for services and functions wanted by society, e.g., management of semi-natural grasslands. By generating an income from using semi-natural grasslands, farmers also create ecological and social functions for the village such as biodiversity and a beautiful landscape (cf.[11]). However, the agri-environmental schemes have been criticized because they do not change farmers' attitudes. Thus, when the action is no longer economically rewarded it is no longer performed[42]. In contrast, many of the actions and the motivation created in the studied villages are longer lasting because they are embedded in the local community.

Village action groups contribute to the sustenance of local farms. Without the village action groups in our study areas there is an obvious risk that these communities would be less thriving. The village action groups seemed to resist the old truth that attitudes/ideas and actions are separated[43]. In our cases, these groups discussed an idea, e.g., that locally produced is good or that they wanted to maintain the open landscape, and then performed actions to make their wish come true.

The multiple functions of farms are closely related to each other. Brodt et al.[13] suggest that a shift to more sustainable farming practices—which rely more on natural ecological processes than on synthetic chemical inputs—will not only produce ecosystem services, but will also inherently benefit rural communities in other ways. This is partly because sustainable agriculture tends to require more locally produced inputs to replace agro-chemicals, and so they will increase local trade and support businesses within communities[13]. Also, there is a trade-off between input intensive production of food and fiber and the provision of ecosystem services[26]. In addition, more industrially organized farms tend to have negative socioeconomic consequences for local communities (see Lobao and Stofferahn[4] for an elaboration). This is partly because small and middle-sized farms and other firms tend to be more embedded in the local community by social and economic relationships[44]. This was the case in our study, where many of the social and economic functions of farms emerged as farmers interacted with the local community.

The quality and quantity of functions coming out from a farm also depends on the scale of the enterprise. Both the overall size of the farm and the size of the farm fields, which tend to be larger on large-sized farms, influence a farm's contribution to wild biodiversity negatively[45,46]. For example, large fields have relatively shorter edge zones where wild species can thrive, and consequently decrease availability of these species[45]. Another reason why large farms may produce fewer functions for the local community is that large farms normally produce large quantities of produce, which in turn need to find processors and markets beyond the local area. For farmers on such farms it is not economically rational to sell locally (cf.[47]). In this case, functions that can emerge out of local food selling such as providing meeting places and value added foods are not provided. Another issue connected to scale is nutrient cycling. A farm with 1000 dairy cows is not likely to spread manure evenly on all fields, but probably only on fields closest to the farm center. Thus, too much nutrients may concentrate in some fields, with leakages and eutrophication as a possible result. In addition, it is seldom practically possible to let so many cows graze all available grasslands. Instead, the animals are restricted to areas close to the farm center, being fed concentrates and hay. In this case, semi-natural grasslands further away from the farm center are not maintained, with reduced wild biodiversity as a result. However, large farms may generate functions small farms do not, such as providing job opportunities on the farm. This was the case in the study cited in this paper, where the largest farm was the only one able to provide jobs to people outside the farm family. It is also important to note that even if small farms seem to have more functions in the local community as the situation looks today, it does not necessarily have to stay this way in the future when many circumstances will change.

In order to refine research to better capture what multifunctionality means from a measurement perspective, it is useful to look at research concerning ecosystem services and ecosystem bundles[26,48]. Many of the functions farms have can also be described as ecosystem services. Foley et al.[48] bundled ecosystem services emerging from different land uses, and found that croplands with restored ecosystem services such as water flow regulation and carbon sequestration produce more ecosystem services than intensive croplands. This can be seen as a parallel to ecological functions of farms. However, more research is needed to look into how the bodies of knowledge on ecosystem services and multifunctional agriculture may be linked.

Conclusion

This was an explorative, qualitative study of four villages and 17 farms in these villages. The villages and the preferences of the members of the four village action groups were different. A larger study, including more villages and farms could have given more robust answers to the questions asked in this paper. Despite the limitations of this study, some commonalities between the four villages were found, and thus some results may be relevant for other contexts as well. First, farmers and village action groups were well aware of the multifunctionality of farming and farms for the rural community. In the four villages, the landscape was not appropriate for industrial farming, and thus the farms in these areas could not deliver as much bulk food as those with the potential of large-scale farms. However, they contributed substantially to the local community with other products and functions. For example, farms offered meeting places in rural areas where few meeting places existed. Farms selling produce locally attracted other rural residents. Local selling of farm products also reinforced local nutrient cycles, and gave farms that could not, or did not, want to develop according to the conventional agro-industrial logic a means to stay in business. Second, the relation between paid and unpaid functions of farms was an issue in all four villages. Farmers were willing to perform unpaid functions generated from the activity of farming as long as they had an income from farming. For example, farmers did not own tractors in order to pull neighbors out of ditches, but since they had tractors for agricultural purposes, they could easily use them for non-agricultural purposes as well.

Finally, the village action movement is an important bottom-up movement that seems to positively stimulate rural communities to support farmers to stay in business, create a local context and a local identity that leads to local production and consumption and local nutrient cycling. When work in the local context is successful, it has a good potential to support the development of sustainable communities and sustainable agricultural production. These also contribute to improved quality of life for farm families and for residents of rural communities. If more functions created by farms and farmers were remunerated and had a market, it is likely that fewer farms would close or decrease

their activity. In order for this to happen, village action groups and farmers need a framework of supportive policies and guidelines on how to work together to achieve shared goals in each community.

In times when cheap oil may become history and the need for climate change mitigation questions Western lifestyles, agriculture and land use will become increasingly contested issues. The same piece of land may be needed as a carbon sink, as a source of biodiversity and for food and fuel production. We need to find ways to evaluate the possible multiple functions of agriculture in order to understand what land use gives the most possible outputs from a systemic perspective. There will be trade-offs and difficult questions to bring up for discussion in society. Should agriculture serve local communities or the global food production? Should agriculture focus on one function, e.g., food production, or on many simultaneous functions, i.e., multifunctionality? What actors have the power to decide on these issues, and who benefits from different outcomes? To answer these questions, it is important to be aware of the functions from agriculture that are lost if one or the other alternative is chosen. Thus, research is needed to describe functions from agriculture in more detail, and in differing contexts. It will also be vital to look closer at the functions agriculture needs to provide in a world of climate change and how we should measure these functions.

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Innovation in vegetable seed production and the role of consumers in the organic and conventional babyleaf chains: The case of Denmark

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Abstract

In this study, the focus is on babyleaf products and the potentials that an increased interest in these products might bring to vegetable seed growers. Case studies on babyleaf products illustrate how consumers perceive babyleaf products and which parameters they give preference to. In addition, aspects of preference for local vegetable products were investigated. The methodological approach has been in the form of two questionnaires presented to consumers in two different chain structures, an industrialized chain (linking actors from 'farm to fork') and an alternative chain where organic produce is delivered to the consumers' doorstep through a box-scheme concept. The participants in the surveys were selected to identify elements that potentially could be used as a spur in innovation and development of new products in the chain and not necessarily to indicate general consumer interests. The overall conclusions are a genuine interest in babyleaf products in both approached chains. In the industrialized chain, 89% of the respondents would like more products and subsequently new niches within seed production are likely to occur. In the alternative chain, 83% of the respondents were very content with the babyleaf product they had received. In addition, these consumers display a profound preference for local products. The paper proposes that seeds and the quality of the seeds play an important role in babyleaf production and should be viewed as, not just a raw material in the chain, but also as the initial step in the babyleaf chain. Dialog among the actors in the chain is essential to meet the consumer demands from both a conventional and an organic perspective. The role of organic seed in organic vegetable productions is discussed.

Key words: babyleaf products, consumer preferences, consumer roles in value chains, spinach seed production

Introduction

Impelled by a global increase in the use of baby spinach (*Spinacia oleracea* L.), the Danish spinach seed production area increased from 2000 ha in 1996 to approximately 6000 ha in 2006[1]. Spinach seed production is favored in Denmark due to temperate climatic conditions, sandy loam soils and not least the years of experience gathered by farmers, seed consultants and research[2]. The vegetable seed industry is increasingly globalized. Each of the world's seed production areas has its competitive advantages and in search of new types for babyleaf production additional seed niches have emerged. The spinach seed industry in Denmark is a worldwide stronghold with a market share of almost two-thirds of the world[1]. Thus, seed farmers in Skagit County, Washington, USA, compete with farmers growing spinach seed in Denmark and cabbage seed in South Africa[3].

Up to 15 million seeds per hectare are used in babyleaf production[4]. This is more than ten times the amount of seeds that are used for bunched spinach. This creates the need for an increased production of seeds of not only spinach, but also for other leafy vegetable types used in babyleaf production. Seed professionals welcome the babyleaf trend and seed growers and seed companies have significant interest in maintaining their respective lead positions within seed production. The Danish region of Zealand, producing approximately two-thirds of the vegetable seeds (besides spinach, various cabbage species and chrysanthemum are widely grown for seed production in the region), has

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invested in motivating growers and researchers in seeds. A high-quality vegetable transplant/product originates from a high-quality seed. However, the quality dimensions of seed have not been given much attention in the value chain literature. Seed is often regarded as a raw material or a production input and not as an integrated part of the chain[5].

The spinach seeds produced in Denmark are distributed worldwide to the traditional markets in Asia and to new strong babyspinach producers in southern Europe who already have highly industrialized supply chains which enable them to supply most of Europe with quality babyspinach and other babyleaf products. This production requires investments in harvest equipment and cooling facilities. Such investments can hardly be borne by small-scale producers alone.

In the Italian babyleaf production, focus is on a well-functioning and unbroken cold chain (temperature-controlled supply chain) directly from harvest to delivery[6]. Therefore, it is possible for Danish supermarkets to sell and market quality babyleaf products from countries such as, e.g., Italy and Spain to Danish consumers all year round. Paradoxically, multiple Danish spinach seeds take a detour of more than 2000 km to southern Europe to become a babyleaf product and then return to Danish supermarkets and the Danish consumers.

Leafy vegetables, particularly babyleaf salads, are largely favored by consumers[6]. In the USA alone, the consumption of spinach increased from approximately 0.5 kg per capita in 1992 to approximately 1.0 kg per capita in 2008[7]. At present, no statistics on Danish consumption are available. Yet, in Denmark imports of spinach increased from 373 tons in 2000 to 2007 tons in 2006[8].

In the USA, outbreaks of *Escherichia coli* in 2006 were linked to spinach and cleared store shelves and resulted in reduced use of spinach[9]. The *E. coli* scare depressed use in the USA by approximately 20% in 2006 compared to 2005[7]. Subsequently, producers worried that consumers would lose confidence in the industry. Spinach consumption in the USA is forecasted to rebound to the 2005 level by 2010.

In the Western world, babyleaf products have a quite strong appeal to consumers as they meet many needs for a modern trendy lifestyle. Consumers are concerned about the food they eat, and convenience is a factor that is increasingly important to them[10]. Further, it is widely anticipated that the demand for food-related convenience will continue to increase[11]. However, convenience is far from the only consumer preference. Many consumers favor organic products and/or local products. It is significant to acknowledge that there are current alternative interests among consumers than those related to highly specialized and industrialized supply chains[12]. Consumer concerns for food safety, animal welfare and the environmental and ecological impact of food production and agro-processing have become increasingly important. These concerns have been exacerbated by several factors, including the trend toward further globalization of the food supply chain[5].

Seed quality has always been of great importance especially when producing vegetables. Seed quality is a broad term and encompasses several attributes of seeds including germination and seedling performance[13]. For the vegetable producers, low and/or uneven seed germination results in products of varying quality and, in worst cases, discarding of the produced lots. The quality dimensions of the seed are quite important in order to avoid, e.g., seed-borne diseases and following blemished products. Today's increased interest for organic vegetables and the arising new market for babyleaf products have put even more emphasis on the quality of the produced seeds.

The seed genetics together with environment, management and technology define the final quality of the product. Greater vertical integration is seen as necessary to maintain quality throughout the 'life' of the product, explaining the emergence of terms such as 'seed to shelf', 'farm to fork' and 'plough to plate'[14]. In 2007, a large project on seed quality in vegetable chains was initiated in the region of Zealand in Denmark. During the project, different salad vegetables were tested for babyleaf production and test seed productions of these were evaluated.

This paper addresses current innovation possibilities, in the value chain that deals with seed for babyleaf production and babyleaf products. The analysis is based on the hypothesis that strengthening the innovation of babyleaf products is closely linked to how the actors in a value chain interact and communicate. In particular, feedback loops between the different actors, including consumers, are decisive for the innovative capacity for differentiation and initiation of new products.

Two separate surveys based on questionnaires were conducted to obtain feedback from consumers on preference for babyleaf products. The first survey included recipients of an organic 'Dogma' box and the second survey embraced consumers visiting an agricultural fair. None of the surveys are based on random sampling. The 'Dogma' box recipients have actively chosen to buy products of local origin. They received a specific babyleaf product in the Dogma box to reflect upon. The 'Agricultural Fair' consumers represent a group of consumers who actively seek out venues where food products are on display. They were provided samples of different kinds of babyleaf products for taste. The two distinct consumer groups were selected on the premise that they could be expected to have interests and preferences that might provide a productive spur for innovations in the babyleaf chains.

The main objective of the first study was to explore among organic 'Dogma' consumers their preference for quality and localized organic babyleaf products. The objective of the second study was to explore overall consumer interest in babyleaf products and, in addition, to obtain feedback on the seed source for leafy vegetable products.

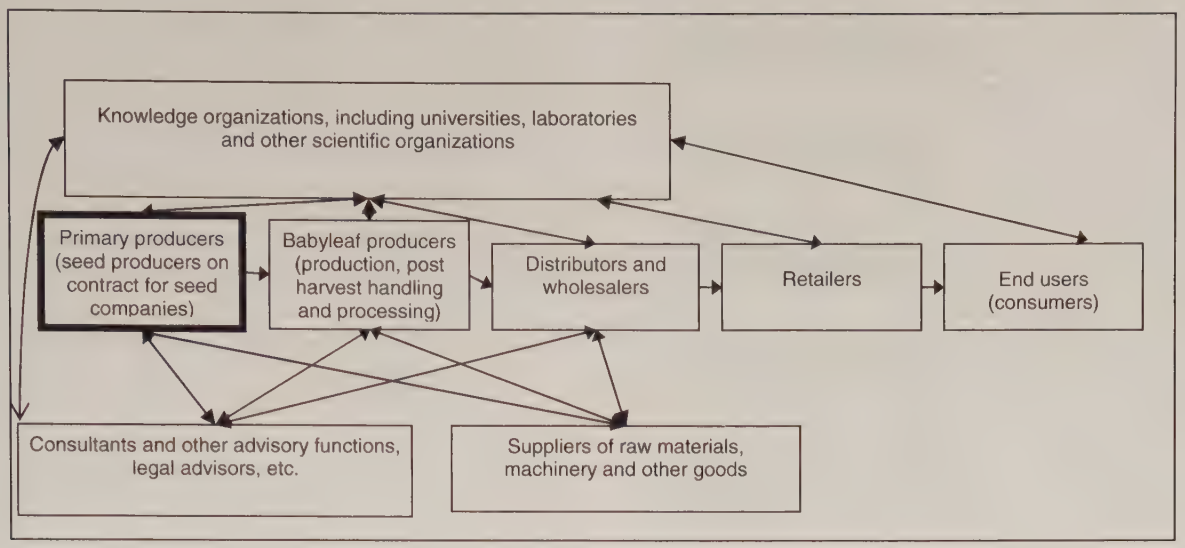

Knowledge organizations, including universities, laboratories and other scientific organizations
Primary producers (seed producers on contract for seed companies)
Babyleaf producers (production, post harvest handling and processing)
Distributors and wholesalers
Retailers
End users (consumers)
Consultants and other advisory functions, legal advisors, etc.
Suppliers of raw materials, machinery and other goods

Figure 1. The babyleaf network modified from a supply chain perspective[18].

Conceptual Framework and Context for the Study

In this study, two types of babyleaf chains were analyzed. The first type was the highly industrialized chain characterized by babyleaf products from multiple suppliers in various countries, distributed to different retailers and subsequently bought by consumers. The second type was an alternative chain based on organic produce where the same company produces the babyleaf products and following packs and delivers directly to the consumers. Analysis of these babyleaf chains was based on the literature regarding supply chain studies[15,16]. A supply chain exists when different actors are linked from 'farm to fork' to achieve a more effective and consumer-oriented flow of products. It is this supply chain approach that raised the issue of consumers' interest in babyleaf products and the seeds used in the production. In the following the supply chain and the value chain concepts will, for simplicity, be integrated and mainly referred to as the babyleaf chain. The supply chain refers to downstream flow of goods and supplies from the source to the retailer and the value chain is flow in the opposite direction[17].

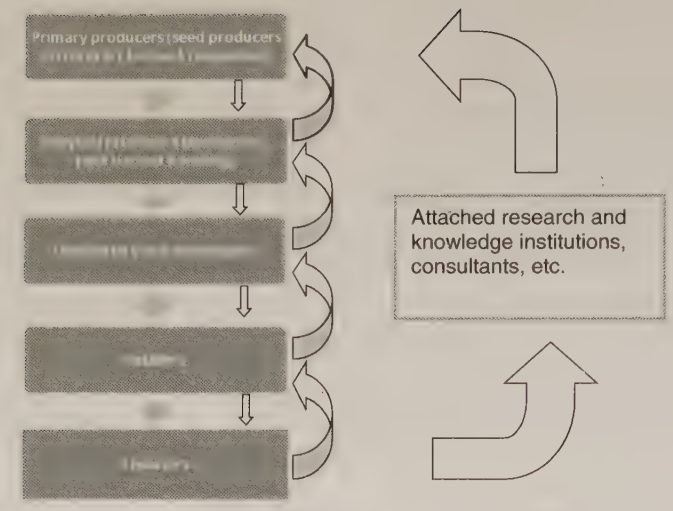
It can be discussed where the chain begins and ends[18]. It might be argued that all chains commence with primary production. When it comes to innovation within vegetables most researches have focused on the part of the chain from food processing onwards. Various inputs to and processes in the chain are based on research and development. In the case of babyleaf produce, the primary production is the production of the seed that goes into the babyleaf production. Figure 1 is a graphical presentation of the babyleaf chain and its network as it is approached in this study. This constitutes the beginning of the chain, and subsequently value is added when the right kind of seed of the right quality is sown and turned into a babyleaf product and further processed and distributed to consumers[1]. The choice of seed both in terms of quality and genetics is of utmost importance for product quality. This is the determinant for resistance against diseases, taste and other parameters appreciated by the consumers following appropriate agricultural practices.

Actors who take an active part in the core processes within the chain are seen as core actors in the babyleaf chain. Consultants providing the core actors with sector-specific knowledge, knowledge institutions developing and disseminating specialized new knowledge, educational institutions supplying a trained workforce and suppliers of raw materials (e.g., fertilizers), machinery and other goods contribute to value and knowledge generation within the chain[18]. As Figure 2 illustrates, a direct feedback loop from the end users to not only retailers but also the whole chain is proposed as this could be a driving force in innovation regarding new products, new mixtures and new uses of babyleaf products.

The system of innovation within babyleaf production is a spring-off from the traditional value chain approach. Primary raw material in the chain from soil to table is manufactured and thereby a value-added effect is seen. While these processes are ongoing, both formal and informal knowledge sharing takes place among the chain core actors. This also includes interaction between the food sector and other actors such as research institutions. Innovation covers not only aspects of radical nature, such as totally new products and processes, but also gradual innovations that typically relate to small adjustments and further developments of products and ongoing processes[19].

The babyleaf spinach chain

Babyleaf is a new type of product within the vegetable assortment. The interest in babyleaf products has spread from the USA and New Zealand to Europe and is now rapidly spreading to the rest of the world. At present, it is



1. The core actors in the babyleaf chain. Most interaction in the chain is one link back and forth.

2. Proposed feedback loops in the chain from end users (consumers) either directly or through attached knowledge institutions, etc. Illustrated by open arrows.

Figure 2. The babyleaf chain and proposed interactions in the chain and feedback loops.

finding its way into the Chinese market, yet mainly as a tourism product and high-grade vegetable[20]. In the USA, one of the fastest-growing segments is prewashed baby-spinach[21]. As such, it is a convenient product, ready to use, fitting perfectly into the modern consumers' request for semi-prepared foods. Spinach is now one of the most popular babyleaf products and is considered the most or second-most nutritious vegetable consumed in the USA[22]. Spinach leaves contain relatively high levels of bioactive compounds such as vitamin C, vitamin A and minerals[23].

Numerous indicators supporting the growing babyleaf market can be found: there is an increasing supply of different kinds of seeds for babyleaf production; shelf meters in supermarkets are growing; products such as mixed babyleaf, rucola and spinach are today stable in most supermarkets and even in discount stores; gourmet restaurants serve babyleaf products; new recipes contain babyleaf products and in addition organic babyleaf products are now slowly entering the market. Unfortunately, no separate statistics on babyleaf products can be found in Denmark and exact figures from supermarkets are not accessible.

Spinach is an annual cool-season crop, and in coastal temperate areas with mild winters it can be grown all year round[24]. A seed such as spinach germinates at temperatures 2 to 30°C, grows at 5 to 24°C and can withstand some frost[25]. In a mild year it is possible to grow babyleaf spinach almost all year round in Denmark, and thereby supply the consumers with local fresh produce. Yet, research has shown seasonal influences to affect the quality of baby spinach leaves[24]. During some periods of the year Danish babyleaf products might not be of the quality consumers want.

To meet the growing demands even in the peak Danish growing season, babyleaf products from southern parts of Europe have entered the market, illustrating the international division of labor throughout the chain.

An alternative food chain

Regarding organic vegetables, the Danish company Aarstiderne.com runs a successful internet-based box scheme concept and delivers weekly boxes of organic fruit, vegetables, meat, fish and bread to Danish families. This is a company that has succeeded with local products and they provide an alternative to the internationalized supply chains. They engage in a novel variant of face-to-face interaction through the internet as a mechanism for aligning producer–consumer networks, as described in Renting et al.[26]. The company itself is responsible for the production of most of the vegetable products that go into their boxes. They also pack and deliver the boxes to the doorsteps of their consumers. In addition, they deal directly with the consumers and therefore receive immediate feedback if something is wrong or missing in the box. In this way they are in charge of the chain for babyleaf production all the way to the consumer (Fig. 1). This short food supply network holds the potential for shifting food production out of its 'industrial mode' and breaking out of the long, complex and rationally organized industrial chains[27]. The concept is an important carrier for creating new and transparent linkages between agriculture and society, producers and consumers. The initiative by the Danish company brings consumers closer to the origin of their food by descriptions of both products and producers in newsletters that accompany the

boxes and on their webpage. The consumers have the option to visit Aarstiderne.com facilities. These facilities offer farm shops and possibilities for social gatherings. This enables the consumer to establish connections with the place/space of production and, potentially, with the values of the people involved and the production methods employed. These successful methods of translation of information allow products to be differentiated from more anonymous commodities and command a premium price if the encoded information is considered valuable by consumers[26].

A key characteristic of this type of supply chain is the capacity to re-socialize or re-spatialize food, thereby allowing the consumer to make new value judgments about the relative desirability of foods on the basis of their own knowledge, experience or perceived imagery. Commonly, these foods are defined by either the locality or even the specific farm where they are produced, and they serve to draw upon an image of the farm and/or region as a source of quality. Short food supply chains on the one hand 'short-circuit' the long, anonymous supply chains characteristics of the industrial mode of food production[27].

Organic seeds

In the organic vegetable production, organic seed is still not available in sufficient amounts[28]. Despite the organic regulations (Council Regulation (EEC) No. 2092/91 of 24 June 1991 on organic production of agricultural products), organic vegetable growers can still be granted dispensation to use non-organically grown seeds for some of their vegetable productions[29–31]. There continues to be difficulties for seed producers with equivalent production of organic and non-organic seeds of the same variety[32]. This leads to organic production of somewhat older varieties, meaning that many of the best new varieties do not reach the organic growers quickly enough[29]. Therefore, to secure wide variety and to allow for new cultivars and improvements of cultivars it might be necessary, to some extent, to allow for non-organic seeds or in-conversion seed in organic productions. Yet, organic vegetable supply chains as a starting point should aim at using only organically produced seeds[33].

Rubitschek[34] has defined different types of organic vegetable growers with different demand to the seed suppliers (with all modulations in between):

- Organic growers, who give priority to organic seed, including growers who are looking for long-term adapted varieties and growers who are looking for the most modern varieties.
- Organic growers, who give priority to genetic characteristics.
- Organic growers, who give priority to less expensive (conventional) seeds.

The latter group of growers feel that the price difference between organic and conventional seed is too large for their business. Hence, they avoid the obligation to use organic seed and specifically choose varieties where no organic seed is available. Consequently, they can use a less expensive conventional seed source.

Babyleaf products are harvested shortly after field germination and it is unknown whether the organic consumer is willing to accept babyleaf products based on conventional seed. For now we therefore assume that the organic consumers' main belief is that organic babyleaf products are based on organic seed.

Babyleaf production has some advantages that consumers might not be aware of. Due to the relatively short production cycle, these productions are not sprayed for pests and diseases. This is not allowed due to fixed waiting periods on agricultural products. This is the period prior to harvest where pesticides may not be applied, since simply washing the product will not remove the applied substance. Lupton's[35] arguement is that the link between health and nature is 'constructed' because many fruits and vegetables, which seem totally natural, are grown using chemicals.

Consumers' preferences

It is assumed essential for consumers not only to buy convenience products, but also to buy a product that has been produced in a certain way. The subjective values are generated by the consumers' wish to buy products with special characteristics or which have been produced in a certain way; for example, organic production from organic seeds or conventional products without the use of genetically modified (GM) seeds. Yet, consumers differentiate in various ways between products and both objective and subjective values are, to a high degree, determined by the individual. A great challenge lies in understanding and decoding the subjective dimensions in order to make products that meet consumer demands or differentiate a product from a competing product.

Dietary debates in the Western world have revolved around the concept that nearly everything can be provided in a pill or capsule[36]. By contrast, the perception that foods themselves are beneficial and can provide much greater clinical and biochemical improvements to patients than pills is a relatively new finding. Clearly, the whole is better than individual components, that is, consumption of diets rich in antioxidants, such as green vegetables, is far better than taking a dietary antioxidant pill[36]. The consumers' interests and the way consumers decide to purchase vegetables is quite complex. Asking consumers in an open-ended interview what they regard as food products of good quality, the answers radiate around four central concepts: taste, health, convenience and naturalness[37]. Health is therefore among several dimensions of food quality in the mind of consumers. It follows that consumers can differ in the weighting of health compared to other quality dimensions such as taste, and that consumers may perceive trade-offs between health properties of a food and other desired quality dimensions, notably taste and convenience. Intensive studies in babyleaf products have revealed quite desirable nutritious aspects of these products[38–40] and more

data are likely to be generated in the years to come. Whether this will affect consumer priorities is a different issue. Another feature is the concept of authenticity: consumers want their food to be trustworthy and produced with consideration for ethical values such as fairness in the supply chain and care for the environment[41]. Consumers' trust develops in the course of a long-term relation, following a form of learning process[42]. If consumer trust in a product is lost, as seen in the case of *E. coli* outbreak linked to spinach in the USA[7], market shares might be very difficult to regain.

Methods

Two questionnaires for two diverse consumer groups have been developed. The first group comprised dedicated organic 'Dogma' consumers. This questionnaire was developed in cooperation with the Danish company Aarstiderne.com to extract consumer perceptions of babyleaf products among their customers. In addition, qualitative interviews were performed with the Head of Vegetable Production and the Organic Advisor at Aarstiderne.com to get more insight into the processes of their management of vegetable production. Aarstiderne.com runs a box scheme concept and delivers weekly boxes of organic fruit, vegetables, meat, fish and bread to 45,000 families in Denmark. They have also added Swedish consumers to the recipient list. About 70% of the food sold comes from Danish producers. This is done by selling through different subscriptions via the internet from the company webpage. This makes the supply chain very short, omitting middlemen. Aarstiderne.com has its own vegetable farming facility at Gram in Denmark, and has produced organic babyleaf products since 2006. Other organic vegetable farmers provide supplementary produce. The concept includes production of vegetable types which are relatively new- or old-type vegetables reintroduced to the Danish consumers, such as purslane. The interview with the Head of Vegetable Production at Aarstiderne.com revealed that the company maintains a closed organic cycle in its production whenever possible. Therefore, varieties of biodynamical or organically produced nature are chosen.

The questionnaire that was sent by Aarstiderne.com was followed up by a brief description including photos of the babyleaf product. The consumers had received the babyleaf product 1 week prior to the survey. The survey took place in December 2008, in order to produce a freshly harvested field babyleaf product out of the peak season. During winter, this box mainly included root vegetables and different kinds of cabbages. Presenting an 'out of season' product probably came as a surprise to some of the respondents. The chosen babyleaf product was cornsalad (*Valerianella locusta*), which can be grown and harvested during winter in Denmark.

The questionnaire was internet based and designed to take less than 5 min to complete. The questionnaire was sent to all 'Dogma' recipients who had received the babyleaf product ($N = 444$). In total, 213 responded to the questionnaire within 48 h (48% response rate). The response rate was evaluated by Aarstiderne.com and found to be within the normal range of what the company normally receives and on which it further evaluates its data. The second group of respondents were selected among a consumer group visiting an agricultural fair during June 5–7, 2009. The Roskilde 'Agricultural Fair' offered a chance to present various babyleaf products and to gather opinions and views from a mixed group of consumers. People attended the fair for several reasons, generally because of interest in farm animals, farm equipment, outdoor activities and market/fair shopping. In 2009, a large food exhibition was held on how to manufacture Danish agricultural products and the questionnaire was placed with the exhibition's stand 'From seed to salad'. Here, various sprouts and babyleaf products were exhibited together with the seeds that go into the production. The regional chef school—Selandia—prepared various salads with sprouts and babyleaf products (e.g., amaranth, komatsuna, red frills, rucola and spinach), for tasting and also recipes were handed out. In total, 112 took the time during the fair to fully complete the questionnaire. The questionnaire might have been too comprehensive as many (43) questionnaires were left only half answered. These were discarded from the survey. As the questionnaires were left unattended at the stand, visitors had to be active to participate in the survey. The consumers who did answer took the time and effort, despite the many priorities attached to a visit at an agricultural fair and must therefore be considered dedicated consumers. There is no reason to believe that the results would have been different if the 43 half-answered questionnaires had been completed. An estimate on how many people visited the stand 'From seed to babyleaf product' while the chef school prepared samples was 2300. This is based on how many recipes were handed out along with the babyleaf salads. It is likely that individuals visited the stand without taking a recipe.

More than 80% of the respondents to this second questionnaire were women and more than half resided in a countryside area. Twenty-eight percent of the respondents were from 16 to 29 years of age, 45% from 30 to 49 years of age and 27% of the respondents were above 50 years of age.

Both groups of respondents, prior to answering the questionnaires, had in different ways been exposed to babyleaf products. The respondent groups represented two different chain approaches and two different consumer groups as described above. The two groups were not identified as representatives of general consumer interests, but instead as groups of dedicated consumers who might possibly identify elements that could be used as a spur for innovation and development of new products or production concepts in the babyleaf chain.

Statistics

The collected data were summarized by descriptive statistics (SPSS 17.0; SPSS Inc., Chicago, Illinois, USA). The

Table 1. 'Dogma' consumers' contentedness with the babyleaf product they received.

Question	Very content	Content	Either content or discontent	Less content	Discontent	Comment
Contentedness, babyleaf product	38% (81)	45% (95)	8% (17)	3% (6)	1% (2)	11% (23)

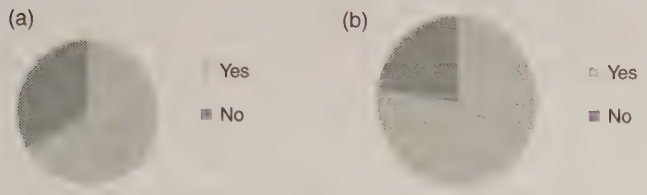


Figure 3. 'Dogma' (a) Consumers' interest in knowing who produces the babyleaf products and (b) preference for Aarstiderne.com's products. Results of an internet-based questionnaire at Aarstiderne.com, December 2008.

'Dogma' survey results are mainly presented by frequency figures. To analyze differences between consumers, the respondents in the agricultural fair survey were divided into three main groups: 16–29, 30–49 and above 50 years of age. The results were also divided into two groups based on the frequency of use of babyleaf products. The significance of differences between the groups was established using contingency (cross tabulation) tables and Pearsons chi-square (at the 5% level of significance).

Findings

'Dogma' consumers—questionnaire I

Table 1 lists the 'Dogma' consumers' contentedness with the received babyleaf product. Eighty-three percent of the respondents indicated that they were very content or content with the babyleaf product.

All respondents were asked to highlight their interest to know who produced the products and, as shown in Figure 3a, 67% of the 'Dogma' consumers showed great interest in knowing who had produced the babyleaf product. The respondents answering 'Yes' were asked if they preferred the products produced by Aarstiderne.com. Here 74% answered 'Yes' (Fig. 3b). As a follow-up, these respondents were asked to respond to where they prefer the origin of the products to be. The majority said they preferred Danish products (Fig. 4). Comments to these questions were all related to either climate (CO_2) or transport. Examples of these included 'As a start the important is good quality and not origin, yet transport and CO_2 also has great importance', 'Organic, good quality and with a production with low CO_2 leakage', 'I do not care if the product is produced by Aarstiderne.com, but it makes sense that it is Danish produce', 'I prefer local and good', 'As short transportation as possible and good quality, then origin is not so important', 'I prefer products grown close by in a CO_2 friendly manner', 'Always products with as little transport as possible (less CO_2)'.

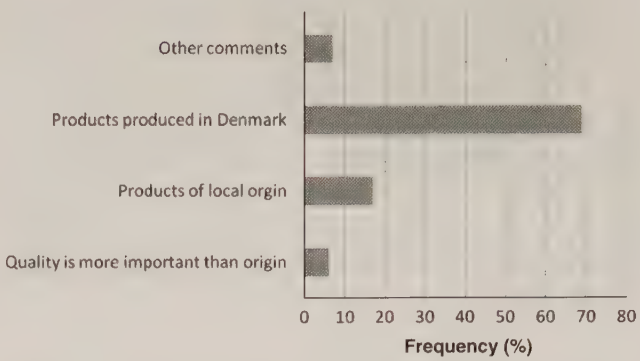

Other comments
Products produced in Denmark
Products of local orgin
Quality is more important than origin
0 10 20 30 40 50 60 70 80
Frequency (%)

Figure 4. 'Dogma' consumers' response (%) to questions of quality and origin of vegetable products. Results of an internet-based questionnaire at Aarstiderne.com, December 2008.

When asked if they were interested in consuming more babyleaf products, 42% answered 'Yes', 27% 'Maybe' and 28% 'No'. There were significantly more respondents answering 'Yes' than 'No'. Eleven percent commented on the question, of which 6% answered that their main interest was babyleaf products in 'season'. The respondents had not been exposed to the fact that the babyleaf product they received was grown in the field. Therefore, many respondents highlighted concerns about how the product was produced (greenhouse with heating). The 42% 'Yes' respondents were then confronted with statements regarding issues that would make them more interested in consuming babyleaf products. Most respondents (32%) indicated a larger selection (Fig. 5). Little emphasis (8%) was put on information of nutrients.

Agricultural Fair consumers—questionnaire II

As illustrated in Figure 6, most respondents thought that the babyleaf products were fresh and crispy and tasted better than traditional lettuce. However, appearance and convenience were also quite central parameters. Not much attention was paid to health issues related to the product.

The 'Agricultural Fair' respondents expressed profound interest in local products (Fig. 7a). Yet, when put into context with relations on appearance, country of origin, price and shelf life, the local parameter scored the lowest (Table 2). Under 'other preferences' 8% mentioned organic products.

The 'Agricultural Fair' consumers were asked how often babyleaf products were used in their household (Table 3) and were then divided into two groups. The first group represented frequent users (one or more times a week) and the second group represented less frequent users (once in a while or never). The frequent users select the babyleaf

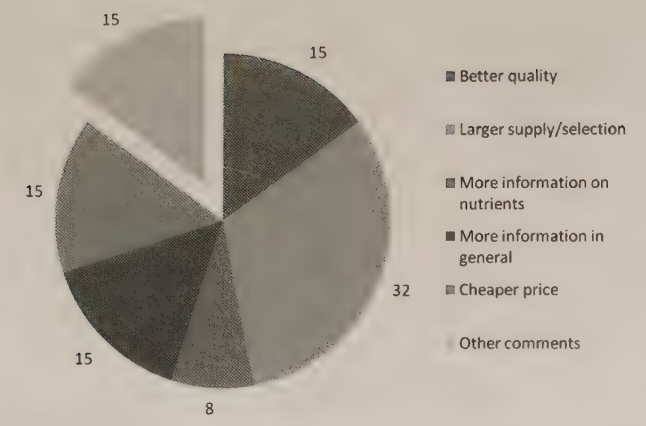


Figure 5. 'Dogma' consumers ($N = 146$) motivations to consume more babyleaf products. Results of an internet-based questionnaire at Aarstiderne.com, December 2008.

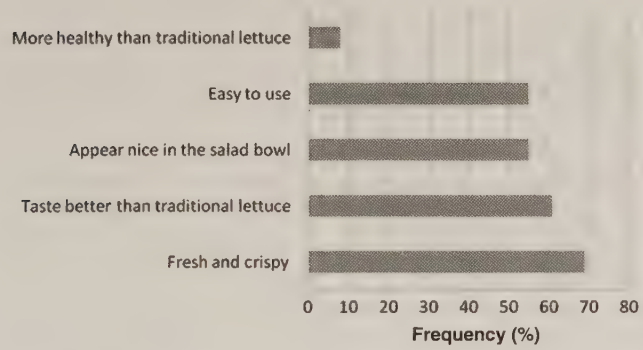

More healthy than traditional lettuce
Easy to use
Appear nice in the salad bowl
Taste better than traditional lettuce
Fresh and crispy
0 10 20 30 40 50 60 70 80
Frequency (%)

Figure 6. Frequency (%) of 'Agricultural Fair' consumers response to yes/no/? questions regarding (a) preference for local produce, (b) preference for knowing seed source, (c) opinion on seed source for organic produce and (d) interest in more babyleaf products on the market.

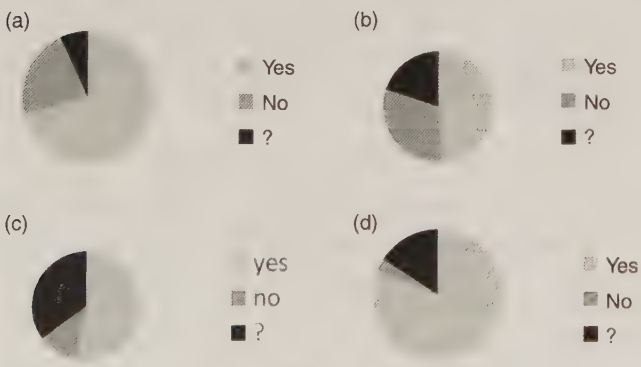


Figure 7. Frequency (%) of 'Agricultural Fair' consumers response to yes/no/? questions regarding (a) preference for local produce, (b) preference for knowing seed source, (c) opinion on seed source for organic produce and (d) interest in more babyleaf products on the market.

products as they taste better than traditional salad ($P = 0.018$). This is the common answer from both female and male consumers. The younger group (16–29 years of age) looked more for product price than the older groups ($P = 0.043$).

Approximately half of those surveyed would have preferred to know the seed source that goes into vegetable production (Fig. 7b). More than half of the 'Agricultural Fair' consumers reflected that organic seeds are always used in organic vegetable productions; yet, more than 30% indicated a question mark on the matter (Fig. 7c). The last question referred to interest in more babyleaf products on the market (Fig. 7d). Here 89% indicated that they would like more products. The questionnaires included pictures of different babyleaf products (common sorrel, yellow and green purslane, and oak leaf lettuce) which at present are not available through the industrialized chains. All products, except for yellow purslane, had the respondents' interest as 48–59 respondents had ticked the box 'I would buy this product if available in supermarkets'.

Discussion

Babyleaf products possess attractive elements for the consumers such as freshness, taste, convenience and appearance. Still, many consumers are not aware of all benefits associated with the babyleaf products and in both the 'Dogma' and the 'Agricultural Fair' survey; only a few respondents highlighted nutrient content or health-related issues to be a driver to buy babyleaf products. In contrast, many surveys have documented an increased focus on health among consumers, which have led to an increased focus on: whether a food is healthy or not; how much fat it contains and what healthy properties it possesses[12]. This contradiction might be explained by consumers associate all fruits and vegetables with healthiness, but, with a few exceptions, they are unable to differentiate more nutritious items from less nutritious ones, as proposed by Shewfelt[43]. There are indications in the recent literature that babyleaf products encompass various health properties[38–40]. It is a production where no chemical fertilizers are allowed and the fast-growing babyleaf cultivars contain less oxalate than their slower-growing counterparts[44]. Whether this will affect consumer preferences is unknown.

The scene was somewhat preset when selecting a group of Aarstiderne.com consumers that subscribe to a 'Dogma' box. In winter that means a lot of roots, tubers and greenhouse lettuce. The Dogma box, which accounts for between 5% and 10% of Aarstiderne.com's orders, keeps the company on its toes by pushing it to discover the limits of what is possible to grow locally[45]. Thus, the 'Dogma' box subscribers seemed to have liked the variation the babyleaf product offered among the more coarse vegetables, as 83% of the respondents either were very content or content with the product. In addition, 42% thought 'Yes' to additional babyleaf products in the 'Dogma' box. Putting a babyleaf product in a 'Dogma' box could be considered the ultimate test for the preference for such a product. Most likely it challenged the organic consumers, beliefs on what could be grown in Denmark in December. Yet, the way they welcomed the innovative product indicates trust in Aarstiderne.com from the majority of the consumers. The respondents

Table 2. 'Agricultural Fair' consumers' ($N = 112$) preferences (%, it was possible to select more than one option) when purchasing vegetable products. Options: appearance; origin (country of production); price; shelf life and local products.

Question	Appearance	Origin (country of production)	Price	Shelf life	Local products	Other preferences
What do you give preference to when you buy vegetable products?	86%	66%	58%	50%	44%	8%

All comments refer to organic produce.

had not been informed that the babyleaf product they had received was grown in the field and therefore their concerns about how the product was produced were quite justifiable. Not surprisingly, 74% of the respondents preferred Aarstiderne.com's own produce. This indicates trust and commitment to the brand and proves that the 'Dogma' box is a deliberate purchase.

The Roskilde Agricultural Fair offered a chance to present various babyleaf products and get opinions and views from a mixture of consumers. People come to the fair for many reasons. The data indicate an overrepresentation of people from rural areas (53%) compared to the average Danish population. This might be caused by the location of the Roskilde Fair and traditionally the display of many activities that attract people with farm and outdoor interests. By contrast many people from larger cities use the opportunity to expose themselves and their children to farm and outdoor activities. More than 80% of the respondents in the questionnaire were women. Similarly, these kinds of food exhibitions attract the female audience. Women are frequently responsible or co-responsible for shopping for food which often leads to a larger representation of women in various investigations of consumption patterns[12].

When asked what parameters they look for in vegetable products, 8% optionally mentioned organic. This proportion is quite similar to the overall share of organic produce sold in Denmark. It is therefore likely to assume that the respondents resemble the average Danish consumers. Consumption of organic food products is still increasing in Denmark and it is estimated that the share of consumers who buy organic food products increased from 4% in 2006 to 7% in 2009[46].

In both the 'Dogma' and the Agricultural Fair survey, the respondents declare to have a preference for local produce. As described above, the 'Dogma' consumers deliberately chose a box where the products are locally or nationally produced and the preference from this group was therefore expected. The Agricultural Fair consumers also expressed a preference for local products. Yet, when put into context with relations on appearance, country of origin, price and shelf life, the local parameter was only selected by 40% of the respondents. In this situation the respondents might think of themselves as shoppers in a supermarket. However, local produce is at present not widely available in Danish supermarkets and is therefore not an optional parameter to look for. The consumers might have the preference for local products but they primarily shop in supermarkets where the produce is not available. Whether 40% of the respondents who prefer 'local' actively seek out local products from farm shops and local markets when possible, or have thought of the display of local products at the Roskilde Agricultural Fair when responding, is another question.

Exploring consumers' views on seed source and 'organic' issues

While many consumers have heard of the term 'organic' and are aware of one of its central features—namely that it is chemical free—most are unfamiliar with organic farming standards and practices[12,47]. The literature suggests some consumer knowledge and awareness of what the term organic means; yet, consumers (sometimes within the same country) are not consistent in their interpretation of what is organic[48]. This is illustrated in the 'Agricultural Fair' questionnaire as 53% assumed that all organic vegetables products originate from organically produced seeds. This is the logical answer that comes into mind. Yet, one must suspect than unfamiliarity with the subject caused this result. Compared to other questions in the questionnaire this was the question where the largest fraction of respondents answered 'do not know'. This could be an indicator of real confusion, as they probably anticipate that seeds used in organic farming are of organic origin, and to some extent lack of knowledge of the organic standards and rules governing organic farming. To maintain integrity in the organic supply chain it is therefore important to highlight these areas to the consumers. As stated earlier, there continues to be difficulties for seed producers in equivalent production of organic and non-organic seeds of the same variety[32]. This leads to organic production of somewhat older varieties, meaning that many of the best new varieties do not reach the organic growers at the same speed as they reach the conventional growers[29]. Denmark has made considerable efforts to meet the demands from the European Union when it comes to producing organic seed for organic agriculture. The Danish seed companies have been involved in practical production; yet, the demands were not quite as expected. Possibly because the cultivars produced were not in demand by the vegetable producers or because too large quantities were produced. Some organic producers apparently try to avoid organic seeds because of, e.g., high costs. Therefore, the Danish production, at present, is limited.

Table 3. 'Agricultural Fair' consumers' ($N = 112$) response (%) to how frequently they use babyleaf products in their households.

Question	Several times a week	Once a week	Once in a while	Never
How often do you use babyleaf products in your household?	36%	17%	43%	4%

In organic babyleaf production seed source is an even more significant issue to consider. It could be argued that the 'in it for the profit' producers using mainly conventional seeds could damage the organic labeling if this is of high priority to the organic consumers. On the other hand, the producers with preference for organic seeds could use it as a brand, generating a surplus on the product. Hughner et al.[49] synthesized the findings of published research on organic food consumption and found environmental concern to be a factor in consumers' attitudes toward organic food. Yet, this is not a driving factor of organic purchase. Perceptions of good health, nutritional benefits and taste are more important in the purchase of organic food[50].

Innovations in the babyleaf chain

The global food system can supply foods from different sources at any time of the year[51]. This ensures the consistency in food variety and quality for consumers around the world. Further, since fresh produce plays a critical role in the competitive strategy of retailers, year round availability is regarded as necessary. Yet, these very real benefits to consumers are associated with several unpaid costs. Shipping or trucking costs are passed on to the consumers; unpriced, environmental costs are not. The chains originating in the southern parts of Europe are very strong and due to favorable climate they can provide babyleaf produce to the rest of Europe on a year round basis. Slowly they are beginning to enter the organic market and increase this production in line with the demand from the retailers. No doubt they consider this a profitable niche.

The short food supply chain, as described in the case of Aarstiderne.com, provides an alternative to the global food system. It is significant to acknowledge that there are current alternative interests among consumers than those related to highly specialized and industrialized supply chains[12]. Many consumers favor, for example, organic products and/or local products. Alternative short food supply networks might not be directly applicable for babyleaf production due to the highly perishable nature of the products. Yet, Aarstiderne.com has succeeded with the production and to introduce a babyleaf product to 'Dogma' consumers 'out of peak season' was much welcomed. In this alternative babyleaf chain, feedback loops from consumers are provided for the whole chain through consumer interaction on the company webpage, e-mail communication and company presence on blogs and through frequent questionnaires such as the one presented here. This direct link between company and consumers ensures that the right amount and type of vegetables enter the boxes.

The two groups of respondents, the 'Agricultural Fair' and the 'Dogma' consumers, both cover consumers who have an interest in babyleaf produce and they are therefore relevant to include in a chain perspective. They have the potential to point at preferences and interests in quality properties that could be a driving force for product development and innovation in a chain perspective. Feedback loops from the consumers to other actors in the chain are very important in order to develop and produce new babyleaf products that maintain these consumers' interest in the produce.

Conclusions and Perspectives

The overall conclusion from the two questionnaires is the genuine interest of Danish consumers in babyleaf products. The consumers would like more products, and therefore new niches within seed production could be given priority among seed producers and the babyleaf chain. Judging from consumer interest in babyleaf products there is plenty of room for innovation processes of new seeds and products in the babyleaf chain.

It seems as though the main drivers of the babyleaf chain originate in southern Europe as they are geared to exploit their competitive advantages linked to good-quality, well-functioning cold chains and potentials for year round supply of babyleaf products. Some consumers favor and expect products of local origin; yet, at present, they seek these options outside the supermarket chains. For organic produce there are Danish producers who favor a closed organic cycle from 'seed to end product' and there might be potentials for this as a signaling value in the chain that can be used to differentiate products on 'quality' parameters.

As positive environmental and health aspects associated with babyleaf products are put forward by various authors[39–41] it could be relevant to look further into these factors and products in general. Both environmental and health aspects might make consumption increase even further. It is therefore essential to focus on seed production of new types of vegetables suited for babyleaf production and, just as important, seeds for a complementary organic production. The seeds and quality of the seeds play an important role in babyleaf production and should be viewed as, not just a raw material in the chain, but as the initial step in the vegetable production chain. It is the seed that determines the characteristics of the products and constant breeding efforts are mobilized to produce the products in demand by the babyleaf industry and consumers. Dialog between the actors in the babyleaf chain is therefore essential for the breeders to meet the consumer demands from both a conventional and an organic farming perspective.

More than ten times the amount of seeds used for a bunched spinach product is used in babyspinach production[4]. Not all types of seeds are readily available for babyleaf production and new niches cannot develop before the seeds are produced.

When it comes to organic seed, the spiral so far has been negative as there are no incentives for many producers in the organic chain to use organic seed exclusively. It is therefore an uncertain business for seed companies to produce organic seed as long as organic vegetable growers can continue to claim first priority to varieties for which no organic seed is available. Questions to put forward in the supply chains might therefore involve: What cultivars do the producers want and in which quantities? Consequently, it will be a crucial element to ensure feedback loops from the vegetable producers and the market as a whole to the seed producers. At the same time, it is necessary to make retailers take steps to require that organic seeds are used in babyleaf products, as the babyleaf producers seem to favor non-organic seeds because this allows a higher profit for organic babyleaf producers. The producers of seeds for babyleaf production cannot drive such a development without cooperation with other actors in the supply chain. It is important to focus on organic seed to secure one of the organic principles—self-reliance, and at the same time close the organic circle from start (seed) to end (product). Integrity should be the driving force that makes the whole supply chain responsible for producing the right type of organic seeds in the right amount. Lack of commitment from the producer's side might, in the long run, jeopardize the organic reputation and brand of different leafy vegetable products.

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Nutritive value of bamboo as browse for livestock

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Abstract

Small farms in Appalachia need management options that diversify income opportunities, are adaptable to new livestock management strategies, and help maintain environmental integrity. Plantings of temperate bamboo (*Poaceae*), including species native to West Virginia, were established to determine the potential nutritive value for small ruminants, such as goats (*Capra hircus*), at different times of the year. The bamboo species we evaluated, included several *Phyllostachys* spp., *Semiarundiaria fastuosa* and *Arundinaria gigantea*, were able to withstand Appalachian winter temperatures and retain some green leaves even in late winter. Although small differences were evident, the nutritive value was generally comparable among species and exhibited similar trends over the season. Total non-structural carbohydrates in bamboo leaves decreased throughout the growing season, and then remained stable or increased during winter. Conversely, crude protein was relatively low in young leaves compared to late season or over-wintered leaves. Concentrations of fiber and protein were sufficient to meet the maintenance needs of adult goats. The ability of bamboo to remain green and maintain the nutritive value throughout winter suggested that it has potential as winter forage for goats in central Appalachia. As an upright browse, bamboo may reduce the exposure of goats to gastrointestinal parasites. Perennial stands of temperate bamboo could prove to be a valuable, multiple-use crop suitable for Appalachian farm operations and easily adaptable to goat production systems.

Key words: nutritive value, bamboo, forage, goats, *Phyllostachys*, *Arundinaria*

Introduction

Bamboo (*Poaceae*, subfamily *Bambusoideae*) is a group of broadly distributed large grasses, including more than 100 genera and at least 1400 species. They contribute to both traditional and developing technologies needed to provide important resources throughout the world. Bamboo are used for human and animal food, fuel, pharmaceuticals, building materials, chemicals and also provide wildlife habitat, stream bank stabilization and erosion control[1–5]. In addition, the potential importance of bamboo as a biofuel and means for carbon sequestration has received recent attention[6,7].

The collection of temperate bamboo germplasm was initiated in the USA during the late 19th and early 20th century by the USDA with most of the research directed toward wood, pulp and forage production[8–10]. When funding for bamboo research dwindled in the 1960s and 1970s, research waned and existing stands were either lost or moved into custodial collections. Subsequent research and development of commercial bamboo-based enterprises in the USA have been mainly directed toward smaller-scale operations such as ornamental and zoological horticulture, and niche markets such as poles and shoots.

Bamboo, a well-known source of food for pandas (*Ailuropoda melanoleuca* and *Ailurus fulgens*), is also consumed by a wide variety of wild animals including ungulates, primates, rodents and insects[11–17]. Many species of bamboo are also employed as pasture or fodder throughout the world. For example, bamboo has been offered to cattle (*Bos* spp.) and sheep (*Ovis* spp.) in Japan[18–20], cattle and yaks (*Bos grunniens*) in Bhutan[18], gayals (*Bos frontalis*) in Pakistan[19], dairy cattle and buffalo (*Bubalus* spp.) in Nepal[20,21], goats (*Capra* spp.) and cattle in Africa[22–24].

However, bamboo has received only modest attention in the USA as forage for livestock, despite historical

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Table 1. Bamboo species information.

Species	Height (m)	Maximum diameter (cm)	Minimum temperature (°C)	Light preference
P. aureosulcata	14	5.6	−23	Full sun
P. bambusoides	22	15.2	−15	Full sun
P. bissetii	12	5.1	−26	Full sun
P. dulcis	12	7.1	−18	Full sun
P. flexuosa	10	7.1	−18	Full sun
P. mannii	8	5.1	−18	Full sun
P. nuda	10	4.6	−29	Full sun
P. rubromarginata	18	7.6	−21	Full sun
Semiarundinaria fastuosa	9	3.8	−21	Full sun
Arundinaria gigantea	6	2.5	−23	Full sun

precedents. The vast acreages of native bamboo (*Arundinarea* spp.), encountered by European settlers, served as habitat for native birds and animals and were indicative of rich alluvial soils[25,26]. These canebrakes were valued as pasture but easily destroyed by overgrazing and now exist only as remnant populations[27]. Research conducted during the mid 20th century, on rangelands of the southeastern USA, confirmed native cane to be of acceptable quality for livestock, but best grazed conservatively together with other forages[9,28–30]. Limited information is available about the nutritive value and potential use as forage of other temperate, non-native bamboos such as those in the genus *Phyllostachys*[31,32]. This may be due in part to the preconception that bamboo grows only in tropical regions, availability of alternative forages and ecological concerns about the risks associated with introduction of non-native plant species.

The bamboo genus *Phyllostachys* contains a number of commercially important species including some that can remain winter green and survive temperatures as low as −28°C. *Phyllostachys* are a running- or spreading-type of bamboo, characterized by a monopodial rhizome system that runs horizontally under the ground, and form groves of evenly spaced culms[25]. Mean total biomass in stands of monopodial bamboo was reported to be near 145 t ha^{-1} with about 57% allocated above ground[6,26]. Above ground production was most rapid in young (<3 years) stands reaching an estimated 6–9 t ha^{-1} yr^{-1} with about 5–15% in leaf mass and a leaf area index (LAI) approaching 12[10,21–23]. Bamboo leaves are likely to contain much higher concentrations of nutritionally important components such as non-structural carbohydrates and protein, as well as minerals such as phosphorus and potassium, compared to other plant parts[33].

Upright, cold-hardy bamboo capable of remaining green throughout Appalachian winter conditions could be a useful source of forage for small ruminants such as goats, while providing materials for other products that could increase or diversify small-farm income opportunities and improve ecosystem integrity. Production of meat goats is one of the fastest-growing livestock enterprises in the USA because of rising product demand from ethnic populations[28]. In contrast to cattle and sheep, goats are opportunistic browsers often preferring herbage near the top of forage plants[29,30]. However, we know little about bamboo survival, growth requirements, productivity or nutritive value for livestock under Appalachian hill-land conditions. Therefore, we established plantings of several species of cold-hardy temperate bamboo, including one species native to West Virginia, with the objective of determining the potential nutritive value for goats at different times of the year.

Materials and Methods

Bamboo and sites

Plantings of non-native, cold-hardy bamboo including *Phyllostachys aureosulcata, Phyllostachys bambusoides, Phyllostachys bissetii, Phyllostachys dulcis, Phyllostachys flexuosa, Phyllostachys mannii, Phyllostachys nuda, Phyllostachys rubromarginata* and *Semiarundinaria fastuosa* were acquired from the USDA-ARS temperate bamboo germplasm center at Byron, GA in April of 2001 or purchased from commercial nurseries in 2002. We also collected specimens of native bamboo, *Arundinaria gigantea* from several locations in West Virginia in 2002 (Table 1). All species were chosen for their potential to survive winter temperatures characteristic of most of West Virginia that include USDA hardiness zones five (−10 to −20°F or −23 to −28°C) and six (0 to 10°F or −18 to −23°C). Clones were acclimated in a greenhouse, planted at two field locations and maintained with periodic applications of balanced fertilizer (14-14-14). The bamboo were not grazed during this study. Soils at the first location, near Bragg, West Virginia (37.80 N, 80.97 W, elevation 850 m), are a mixture of fine loamy, mixed, mesic Typic Hapludults and loamy-skeletal, siliceous, active, mesic Typic Dystrudepts. Soils at the second location, near Alderson WV (37.70 N, 80.66 W, elevation 550 m) are a mixture of fine-loamy, mixed, active, acid, mesic Fluvaquentic Endoaquepts and fine-loamy, mixed, superactive,

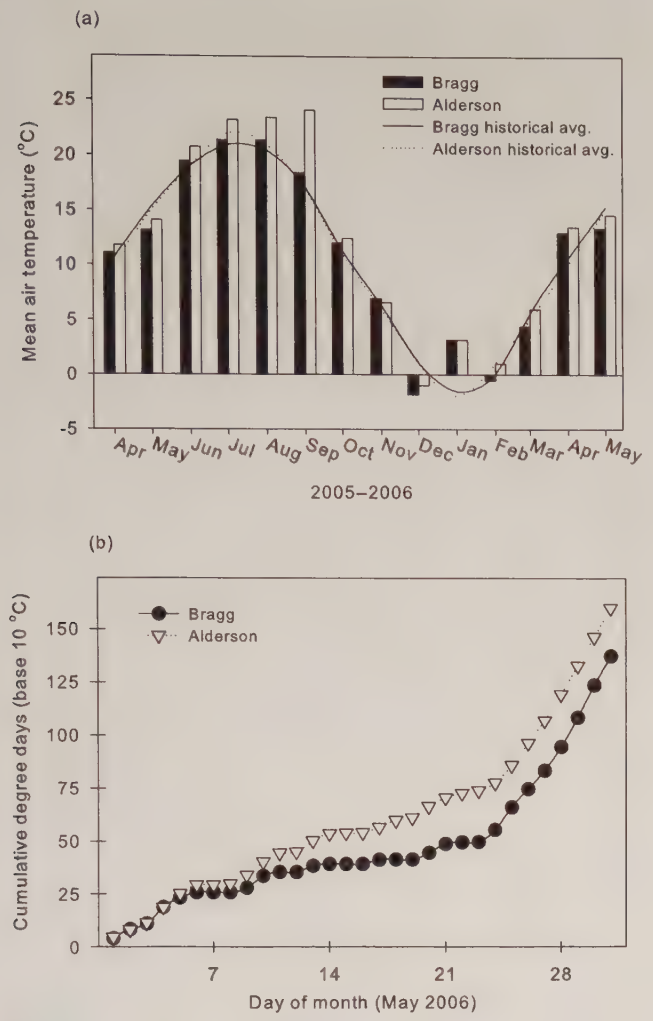

Figure 1. (a) Mean air temperature and (b) cumulative degree-days for Bragg and Alderson sites.

mesic Oxyaquic Fragiudalfs. The lower-elevation Alderson site has a slightly warmer average growing season than the Bragg site (Fig. 1a).

Average composition of temperate bamboo foliage (green leaves and attached petioles) was determined from grab samples collected from all species in late July (mid-summer) and mid-September (late summer) 2003 and 2005 and winter (February and January) 2004 and 2006 (Table 2). Additional samples of *Phyllostachys* foliage were collected, on August 29, and October 13, 2005, to provide more details about intraseasonal patterns of forage composition and possible site effects. Emerging shoots (elongating culms+leaves and petioles) were collected from *Phyllostachys* species on May 11 and June 15–16, 2005 and on May 9 and May 25, 2006 to compare the composition of young shoots to more mature foliage. Bamboo plots were mowed to a height of about 7.5 cm on April 10–11, 2006, about 4 weeks before sampling. All samples were dried (55°C) in a forced-air oven, ground (Wiley mill, 1 mm sieve) and stored in a freezer (−21°C) until analysis.

Chemical analyses

Total carbon (C) and nitrogen (N) concentration were determined by dry combustion[34] with a FlashEA 1112 NC Analyzer (CE Elantech, Lakewood, NJ). Total N data were multiplied by a factor of 6.25 to estimate the crude protein (CP). Total non-structural carbohydrates (TNC) were determined by an automated hydrolysis method[35]. Acid detergent fiber (ADF) was determined by the procedures of Van Soest et al.[36] using an ANKOM 200 Fiber Analyzer (Ankom Technology Corp., Fairport, NY). Acid detergent lignin (ADL) was determined by subjecting ADF residue to 72% sulfuric acid. Cellulose was calculated by subtracting ADL from ADF. Ash content was determined on 0.5 g samples and reported as the percentage of total plant dry matter remaining after combustion in a muffle furnace at 525°C for 3 h. We used the values from total C, N, TNC and the ADL to calculate C : N, TNC : CP and lignin : N ratios.

Statistical analyses

The influence of species and season on the composition of bamboo leaves was determined with SAS 9.2 and PROC MIXED (SAS Institute, Cary, NC) using a model that contained both fixed (species) and random (side) effects and treated sample dates as repeated measures[37,38]. In other analyses, intraseasonal trends and intersite differences, within the genus *Phyllostachys*, were analyzed for leaf samples, collected monthly from June to October 2005 and in January 2006, by considering individual species as independent replicates ($n = 8$) and sample dates as repeated measures. Finally, we compared *Phyllostachys* shoot composition in early May 2005 to that in early May 2006 and composition in early May 2006 to that in late May 2006.

For all analyses, assumptions of data normality were evaluated and appropriate data transformations identified with SAS/ASSIST. Covariance structures were selected to minimize Akaike's Information Criterion. Pairwise comparisons of means were adjusted by the Tukey–Kramer method assuming a value of 5% as the minimum criterion for significance. Values indicated in text and graphs are the arithmetic mean, ± standard error of the mean, expressed on a dry matter basis.

Results

All species of bamboo were able to withstand Appalachian winter temperatures during the period 2001–2006 and retain some green leaves even in late winter. The experiment was terminated and all bamboo killed with the application of Roundup Ultra® [*N*-(phosphonomethyl) glycine; Monsanto, St. Louis, MO] applied at 26.4 ml l^{-1} in June 2006.

Composition of cold-hardy bamboo

Total leaf C, averaging 48.1 ± 0.1%, did not vary among bamboo species or with season. However, there was a

Table 2. Sample dates for temperate bamboo foliage and shoots.

Sample	Sample description	Sample dates	Additional comments
Foliage from all species	Green leaves and attached petioles	July 21–22, 2003 and July 25, 2005	Mid-summer
		September 9–10, 2003 and September 20, 2005	Late summer
		February 19, 2004 and January 27, 2006	Winter
Phyllostachys foliage		August 29 and October 13, 2005	Additional sample dates
Phyllostachys shoots	Emerging shoots (elongating culms, leaves and petioles)	May 11 and June 15–16, 2005	Plots were mowed to a height of 7.5 cm on April 10–11, 2006
		May 9 and May 25, 2006	

Table 3. Nutritive value of foliage from cold-hardy bamboo species[1].

	% of dry mass						Ratios		
Species	**TNC**	**Crude protein**	**ADF**	**Cellulose**	**ADL**	**Ash**	**C:N**	**ADL:N**	**TNC:CP**
P. aureosulcata	9.4	15.5^{AB}	34.8^{ABC}	24.4^{AB}	10.4	7.4	19.7^{AB}	4.2^{AB}	0.62
P. bambusoides	8.3	15.7^{AB}	34.0^{ABC}	24.6^{AB}	9.4	7.6	19.3^{AB}	3.9^{AB}	0.54
P. bissetii	9.4	16.5^{AB}	34.2^{ABC}	23.7^{AB}	10.5	8.7	18.4^{AB}	4.0^{AB}	0.59
P. dulcis	10.7	16.1^{AB}	31.5^{C}	22.6^{B}	8.9	6.6	19.1^{AB}	3.5^{AB}	0.67
P. flexuosa	9.2	16.3^{AB}	34.8^{ABC}	25.8^{A}	9.0	7.7	18.5^{AB}	3.5^{AB}	0.57
P. mannii	7.8	15.2^{B}	36.2^{A}	26.1^{A}	10.1	7.2	20.2^{A}	4.2^{A}	0.52
P. nuda	9.6	15.3^{B}	34.7^{ABC}	25.1^{AB}	9.5	6.9	19.8^{A}	3.9^{AB}	0.63
P. rubromarginata	7.5	15.6^{AB}	36.2^{AB}	25.3^{AB}	10.8	7.8	19.6^{AB}	4.4^{AB}	0.49
Semiarundinaria fastuosa	10.2	17.9^{A}	32.9^{BC}	24.4^{AB}	8.5	7.3	17.0^{B}	3.0^{B}	0.58
Arundinaria gigantea	8.9	14.8^{B}	35.0^{ABC}	26.2^{A}	8.8	6.7	20.6^{A}	3.7^{AB}	0.61
Season									
Mid-summer ($n = 38$)	10.5^{X}	15.2^{Y}	33.1^{Y}	25.1	8.0^{Z}	6.9^{Y}	20.2^{X}	3.4^{Y}	0.69^{X}
Late summer ($n = 37$)	8.9^{XY}	15.6^{Y}	35.2^{X}	25.2	9.9^{Y}	7.4^{XY}	19.5^{X}	4.0^{X}	0.57^{Y}
Winter ($n = 36$)	8.0^{Y}	16.9^{X}	35.2^{X}	24.2	11.0^{X}	7.9^{X}	18.0^{Y}	4.1^{X}	0.48^{Y}
Overall									
Mean (SEM) ($n = 111$)	9.1 (0.3)	15.9 (0.2)	34.5 (0.3)	24.8 (0.2)	9.6 (0.2)	7.4 (0.2)	19.2 (0.2)	3.8 (0.1)	0.58 (0.02)

[1] Samples of green leaves and petioles were collected during mid-summer (July 21–22, 2003 and July 25, 2005), late summer (September 9–10, 2003 and September 20, 2005) and winter (February 19, 2004 and January 27, 2006) from two locations. Data are for total non-structural carbohydrate (TNC), crude protein (CP) (calculated as $N\% \times 6.25$), acid detergent fiber (ADF), cellulose, acid detergent lignin (ADL), ash, total carbon (C) and nitrogen (N). Within each column, superscript letters denote significant Tukey–Kramer adjusted differences among species or seasons ($P \leqslant 0.05$).

significant ($P \leqslant 0.05$) main effect of species or season on the other foliage characteristics (Table 3).

TNC of leaves, with an overall mean of more than 9%, varied with season, decreasing from 10.5% in late July to 8% in the winter. CP averaged nearly 16% across all species and seasons with the highest content observed for *S. fatuosa* and the lowest content observed for *P. nuda*, *P. mannii* and *A. gigantea* (Table 3). CP varied little during the summer growing season but increased during winter.

ADF (mean 34.5%) varied among species and with season. Among species, *P. dulcis* contained the lowest concentration of ADF, whereas *P. mannii* and *P. rubromarginata* contained the highest. Mean ADF increased from late July to late September but remained unchanged in mid-winter. Cellulose varied among species, being least in *P. dulcis* and greatest in *P. mannii*, *P. flexuosa* and *A. gigantea*, and was the only variable that did not vary with time, remaining at nearly 25% throughout the year. Average ADL, approaching 10%, did not vary among species, but increased with each successive sampling. Similarly, the ash content (mean 7.4%) did not vary among species, but increased from late July to mid-winter.

The ratios of total C : N (mean 19) and ADL : N (mean 4) varied with species and season. In both instances, lowest average values were observed for *S. fastuosa*, but the range among species was narrow. Average C : N ratios decreased from July to winter, whereas ADL : N ratios increased from July to September. The ratio, TNC : CP, is thought to link nutritionally important indicators of energy and protein in herbage[39]. Clear differences among the various bamboo species were not apparent but ratios decreased from early to late season reflecting the increased N content of herbage.

Intra-seasonal and site patterns in Phyllostachys *foliage*

Seasonal and site variations for some *Phyllostachys* leaf characteristics were observed during the 2005–2006 season.

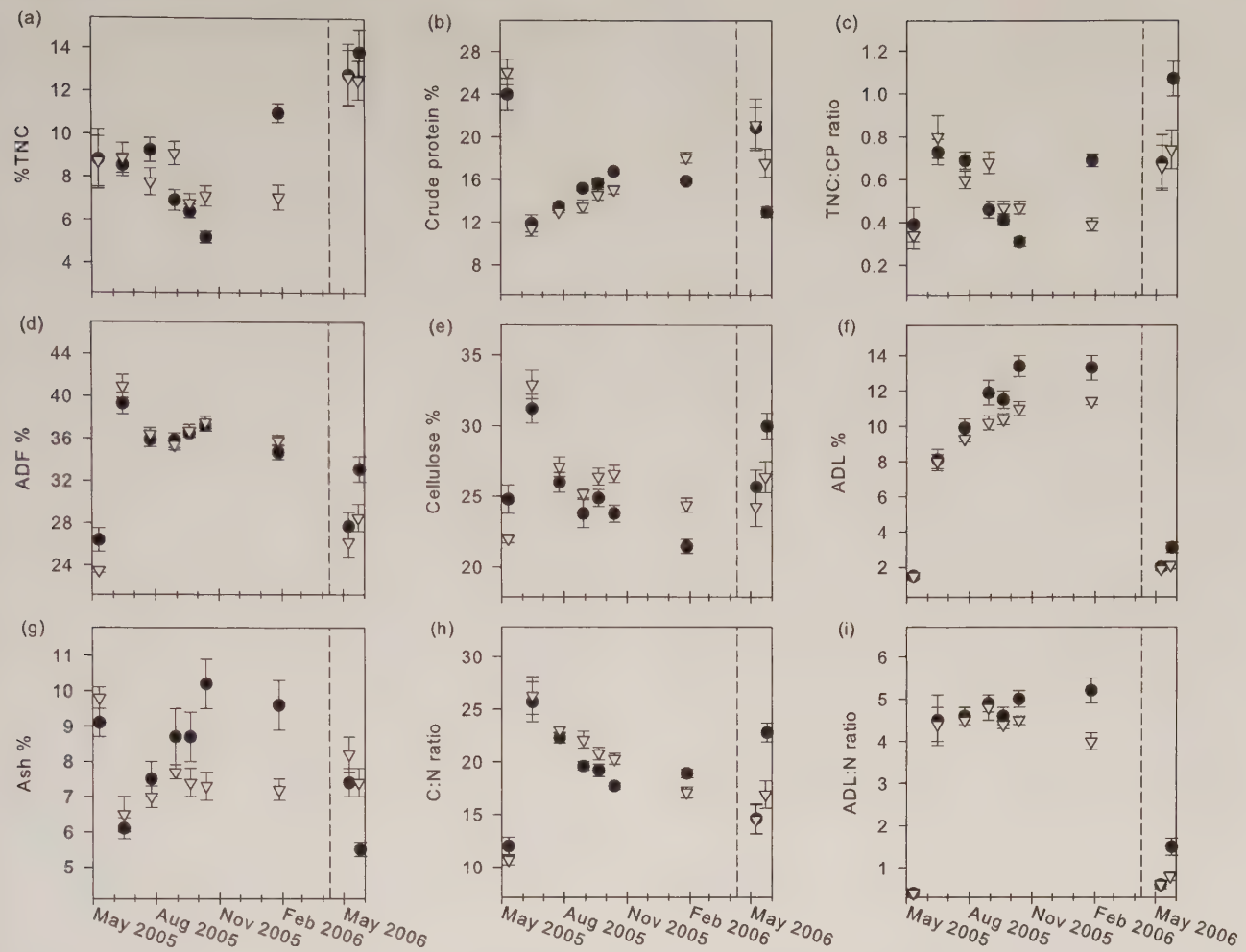

Figure 2. Seasonal trends of (a) TNC, (b) CP, (c) ratios of TNC:CP, (d) ADF, (e) cellulose, (f) ADL, (g) ash, (h) total C:N and (i) ADL:N in shoots and leaves of *Phyllostachys* spp. growing at two sites (Alderson • and Bragg ▽). Values (combined species, means ± SEM) are from entire shoots collected on May 11 ($n = 3$–7) and June 15–16 ($n = 6$–8) 2005 and on May 9 ($n = 7$) and May 25 ($n = 7$–8) 2006. Leaves (including petiole) were sampled in 2005 on July 25 ($n = 8$), August 29 ($n = 7$–8), September 20 ($n = 8$) and October 13 ($n = 8$) and in 2006 on January 27 ($n = 6$–8). Bamboo plots were mowed to a height of about 7.5 cm on April 10–11, 2006 (dashed line).

TNC decreased at both sites during the 2005 growing season, most clearly at the Alderson site, declining from 8.6% in June to 5.2% in October, compared to 8.9 and 7.1% at the Bragg site (Fig. 2a). Concentrations of TNC remained constant at the Bragg site through late January but TNC increased at the Alderson site, reaching levels comparable to the previous June.

Crude protein in bamboo leaves increased during the growing season, from about 11.5% at both sites in June 2005 to between 15 and 17%, by mid-October (Fig. 2b). CP was slightly higher at Alderson during most part of the year, but meaningful differences between the sites were evident only in October and January. Highest values of foliage CP were observed at the Bragg site during winter 2005, whereas CP remained relatively constant at Alderson, from fall through January 2006.

Seasonal patterns of TNC : CP ratios resembled those observed for TNC, declining from mean values in June, at the Alderson and Bragg sites, of 0.73 and 0.81, respectively, to 0.31 and 0.47, in October (Fig. 2c). Ratios declined slightly at the Bragg site, from October through January, but increased at the Alderson site to 0.69, close to June values. Differences between sites were observed in August and October (Bragg>Alderson) and January (Alderson>Bragg).

Concentrations of ADF in bamboo leaves decreased at both sites, from about 40% in June to 35% in January 2006 (Fig. 2d). Although about 2% higher at the Bragg site, cellulose content in bamboo leaves decreased at both sites from 32% in June to 22.7% by January (Fig. 2e). Unlike ADF and cellulose, ADL, increased from 8% in June at both sites, to about 11 and 13% for Bragg and Alderson sites, respectively, in October and January (Fig. 2f).

Ash content of leaves increased at the Alderson site from about 6% in June to about 10% in October and January (Fig. 2g), but did not vary at the Bragg site, and remained nearly 7% throughout the season. Differences between the

two sites became greater as the season progressed, peaking in October.

The C : N ratios of bamboo leaves decreased from 25 in June to 18–19 in January (Fig. 2h) with differences between the sites evident in October samples. In contrast, ADL : N ratios changed a little during the year (mean 4.6), with site distinctions detected only in January (Fig. 2i).

Phyllostachys *shoots*

The composition of young *Phyllostachys* shoots (culms and leaves) was distinct from more mature leaves, and could vary quickly with time as they elongated and segregated more distinctly into component elements such as culms, petioles and leaves.

The concentrations of TNC, measured in early May, were higher in 2006 than in 2005, but did not differ between the two sites (Fig. 2a). A similar pattern, observed for TNC : CP ratios, was attributable to these increased values of TNC (Fig. 2c). Mean shoot TNC (12.7 ± 0.9%) and TNC : CP ratios (0.67 ± 0.08%) in early May 2006 were comparable to winter foliage values at the Alderson site but higher than those at the Bragg site.

With these exceptions, the composition of bamboo shoots, measured in early May 2005 and 2006 did not vary between years or sites. CP in shoots (22.5 ± 1%), was about twice that of leaves (Fig. 2b). Mean ADF (26.4 ± 0.7%), cellulose (24.6 ± 0.6%), ADL (1.8 ± 0.1%), C : N (13.4 ± 0.7%) and ADL : N ratios (0.53 ± 0.04%) in shoots were lower than leaves (Figs. 2d–f,h,i). The ash content of shoots was comparable to bamboo leaves (8.4 ± 3%, Fig. 2g). By late May 2006, only 2 weeks after initial measurements, CP and ash content in shoots decreased, while TNC, ADF, cellulose and ADL in young shoots increased. Greatest changes in nutritive value were observed in plants growing at Alderson, a relatively warm site that accumulated 40–50% more growing degree-days than the Bragg site between the two sampling dates (Fig. 1b).

Discussion

The values of TNC observed for bamboo leaves in this study are only about 50% of the more than 200 mg g^{-1} reported for *Phyllostachys pubescens*[33], but they compare reasonably to other Appalachian silvopasture forage species[40,41]. Concentrations of TNC in bamboos have been reported to be highest in leaves>branches≥rhizomes≥stems≥roots with rapid spring growth of new shoots corresponding to reduced concentration of TNC in the rhizomes[33]. Although TNC generally declined during the growing season (Table 3), high amounts of TNC and CP were observed at the Alderson site during winter and at both sites in *Phyllostachys* shoots in spring (Fig. 2a,b).

Mean concentrations of CP in bamboo leaves (Table 3) compare well with those from recent studies of *Phyllostachys*[31,32,42], and with values for *Arundinarea*[9]. Although lower than the range reported for some leguminous browse species[43] and *Paulownia*[44], bamboo leaf CP was comparable to other temperate browse species consumed by goats[45–47]. Concentrations of CP in *Phyllostachys* leaves were an order of magnitude greater than expected in mature culms[13,42]. High CP in *Phyllostachys* shoots, in excess of 20% dry weight, were consistent with values commonly reported for edible bamboo shoots[48,49].

The balance of TNC : CP suggests that bamboo foliage can meet the maintenance or growth needs of goats[50,51]. The TNC : CP quotients of bamboo ranged from about 0.35 to 0.8 and were slightly greater than cool-temperate grasses managed for forage productivity and nutritive value in silvopasture[30,47].

Although the levels of TNC and CP observed in young culms (shoots) infer a high forage nutritive value, significant grazing of elongating shoots would likely have adverse impacts on stand productivity and sustainability by consuming new growth and thus preventing the formation of new leaves, and also because young bamboo culms (shoots) can break easily[52]. Shoots also have considerable economic value as a fresh crop to supply food-grade produce to various niche markets. The differences between early and late May 2006 indicated that shoot composition changes rapidly as culms mature. Similar short-term (<14 days) decreases in protein content and increases in fiber content were reported in edible bamboo shoots[53] and are associated with the mobilization of stored carbohydrates from rhizomes and translocation of nutrients from senescing to developing leaves and roots[33,54,55].

Concentrations of ADF, cellulose and lignin were higher in these bamboo species than in leaves of other potential browse species including *Paulownia*[44], locust (*Robinia* spp.), mimosa (*Albizia julibrissin*)[43], autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*) or honeysuckle (*Lonicera japonica*)[47]. Ash content in bamboo leaves and shoots (Table 3, Fig. 2g) was similar to published values[13,48] and was expected to be about 3–4 times higher than in mature culms or rhizomes. The ash content of bamboo is composed of silica together with metals such as calcium and potassium[56].

Bamboo leaves contain a number of biologically active components with potential health benefits[57,58]. However, some parts of the bamboo, notably the shoots may also contain toxic compounds, such as oxalic acid and cyanogenic glycosides[49,59,60]. Some bamboo species (e.g. *Bambusa vulgaris* from Brazil) have been reported to contain unidentified compounds toxic to horses[61]. Unlike other browse species or plants that have been considered as candidates for biofuel production, such as hybrid poplars (*Populus* spp.), bamboo is unlikely to contain significant amounts of polyphenolic plant secondary compounds such as tannins that can affect the forage nutritive value[46,62,63].

Bamboo may help mitigate the effects of gastrointestinal nematodes (GIN), such as the barberpole worm (*Haemonchus contortus*), a major parasite of small ruminants in the southern USA. In contrast to cattle and sheep, goats are

browsers that prefer to graze plants from the top down[29]. However, when browse is scarce, goats will graze traditional grasses and legumes in pastures contributing to problems with GIN control. In infected animals, adult female GIN shed eggs, which pass onto pastures with livestock feces. Under favorable conditions, larvae hatch, crawl up forage into the grazed horizon, and are consumed as livestock graze. Larvae are more concentrated in lower levels of the plant canopy[64]. Goats have very poor tolerance of GIN loads, having evolved to avoid larvae by browsing above the infested layers. The detrimental effects of GIN are exacerbated because of increased resistance of GIN to chemical anthelmintics[65]. By providing a source of browse with a higher grazed horizon at critical times, bamboo may help reduce infection with GIN, especially *Haemonchus*[66,67].

Temperate bamboo seem particularly well adapted to the heterogeneous mosaic of light and soil conditions that characterize Appalachian silvopastures because they can adapt morphologically to low-light conditions. More importantly, some genera are able to physiologically integrate environmental heterogeneity by translocation of photosynthetic assimilates and nutrients, such as N, from zones of relatively high availability to biomass located in zones of relative paucity, primarily via translocation through rhizomes, thus stabilizing productivity[62–64]. In the present study, decreasing C : N ratios in foliage during the winter season were associated with increasing concentrations of leaf-N, indicative of acclimation to retain photosynthetic capacity accompanied by reallocation of non-structural carbohydrate from leaves to culms.

Adaptation of temperate bamboo will require further research to develop management strategies that effectively incorporate controlled grazing to maintain the productivity and sustainability of temperate silvopastoral grazing systems[68]. Too little grazing may result in competition between bamboo and overstory trees for resources, such as light or water[69,70]. In addition, some species of *Phyllostachys* are thought to contain allelopathic substances, such as phenolic acids, that could interfere with the growth of other forage species[71]. Conversely, overgrazing can damage bamboo by reducing culm density or size, and damage or hamper regeneration of tree species[18,27,72]. However, controlled grazing, especially with browsers such as goats, alone or together with cattle, may contribute to sustained pasture productivity by maintaining desirable botanical composition of forage species, controlling undesirable invaders and promoting regeneration of tree species[18,29,73,74].

Cold-hardy bamboo species seem capable of retaining green foliage and nutritive value throughout winter months, a time when few other green fodder options are available. The upright growth habit of bamboo makes this fodder accessible to livestock even under snow conditions and could help reduce initial GIN loadings in goats in the spring. High potential for biomass production, coupled with the possibility of photosynthesis early and late in the growing season, suggest that in addition to serving as a source of forage for livestock, bamboo could be managed as an effective carbon sink[6,75]; or a source of raw material for biofuel, pulp wood or fresh shoot production[76].

More research is needed to expand the nutritional database beyond the few bamboo examined in this study and to establish criteria for selecting from among species with comparable nutritive qualities. In addition to selecting a suitable species, successful integration of bamboo into small ruminant production systems will also require cultural recommendations, tailored to local conditions, needed to establish forage bamboo, maintain its productivity and quality, and manage its growth. Potential concerns about invasiveness of monopodial bamboo, such as *Phyllostachys*, may be allayed by known control strategies including barriers, cultivation, spraying or intentional overgrazing[77], but these may be costly and result in unwanted environmental consequences. Thus, decision support tools are needed to help identify and compare economic and environmental consequences of bamboo-based enterprises, in order to adopt prudent measures that protect the environment[78].

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Organic food: What we know (and do not know) about consumers

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Abstract

This paper reports on the latest contributions to over 20 years of research on organic food consumers. There is a general consensus in the literature on the reasons why people buy organic food. However, there is also a gap between consumers' generally positive attitude toward organic food and their relatively low level of actual purchases. Product differentiation based on intangible features, such as credence attributes such as organic, in fast-moving consumer goods categories is enjoying rapid growth. However, there are many difficulties with research in this area, including the errors inherent in research that relies on consumer self-reporting methodologies. Further, in relation to organic food, there is a divergence between consumers' perception of its superior health features and scientific evidence. Fresh fruits and vegetables are of vital importance to the organic sector as they are the entry point for many customers and account for one-third of sales. Further, although there is a small proportion of dedicated organic food buyers, most sales come from the majority of buyers who switch between conventional and organic food purchases. This paper identifies the practical implications for generic organic food marketing campaigns, as well as for increasing sales of specific products. It concludes with suggested priorities for further research.

Key words: organic food, consumers, research, purchases, segmentation

Introduction

Organic food has been analyzed from many perspectives and in many countries. It contributes to an emerging paradigm for food production which relies on biology, ecology and sociology rather than more one-dimensional chemical and physical management approaches[1]. Building upon over 20 years of research, there is now a substantial body of information on how to market organic products. Recent examples include the studies by Hughner et al.[2] and Pearson and Henryks[3]. In addition, research has been completed, which contributes to our understanding of specific aspects of how to market organic products. This includes consumer behavior for local organic foods[4] as well as consideration of 'low input' and organic foods[5] through to how the organic quality assurance system may be used to develop a marketing strategy[6] and decision-making processes for organic food consumers[7].

As this proliferation of previously mentioned articles indicates, understanding human behavior in the context of food purchases remains a frontier for scientific enquiry. While it is generally accepted that our food habits are largely determined by attitudes that are acquired in childhood, and that these evolve due to changing circumstances and experiences, it is the diversity of individuals, the multiplicity of products which, when combined with the enormous number of purchases over a lifetime, makes understanding food purchases so challenging[2]. Further, purchases of relatively low-value, low-involvement products from multiple locations add further challenges[8], although it is interesting to note that sales of many of these products which are differentiated with intangible features, such as organic and Fair Trade, which are both examples of credence attributes, are enjoying much higher growth rates than the main market. Credence attributes are difficult to judge even after purchase[9] (such as environmental credentials) in contrast to search attributes which may be evaluated prior to purchase (such as price) and experience attributes which may be evaluated after purchase (such as taste)[10].

This paper continues by reviewing the major areas in which research has contributed to our understanding of the food supply chain and the implications that this has for organic food. This is followed by identification of what we

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know about organic food consumers in relation to why they buy organic food, who they are and what they purchase.

Food Distribution

In terms of increasing our understanding of food purchases, a number of valuable insights have been provided by investigating the food supply chain. At the global level, the organic industry is estimated to be in excess of $US40 billion[11]. However, at the national level, supermarkets tend to dominate the distribution of food in most developed countries. For example, in the UK, four chains account for around 80% of sales[12], whereas in Australia only two supermarket chains control a similar percentage of the market. The supermarket business model relies on high sales levels at relatively low profit margins. Their customer proposition focuses on convenient 'one stop' shopping from their wide range of products, often in excess of 30,000 in one store, at relatively low prices, with the added benefits of long opening hours and ease of parking. Many supermarket chains offer a wide variety of organic products, including private and own brand organic labels. There is also significant expansion in the range of organic products available in supermarkets[2,4]. This includes processed products, such as organic tomato sauce and organic frozen pizzas. These provide more choice for existing consumers of organic products as well as offering the organic option to mainstream customers for whom convenience is important. However, supermarkets are not the only retail outlet in the food supply chain.

Non-supermarket retail outlets, or complementary retail outlets, often referred to in a somewhat dismissive manner as alternative retail outlets, also supply food, and perhaps more importantly, are an area in which many food supply chain innovations are occurring. These outlets appear to be emerging from community level interest in creating food-supply chains that are resilient as well as supporting environmental, social and economic goals and are often seen as 'local' food networks[13,14]. Many of these appear in different formats, including organizations that use co-operative business structures, independent outlets, farm shops, farmers, markets, community-supported agriculture schemes and productive gardens. Further, many of these non-supermarket retail outlets provide organic food. However, all the previously mentioned retail outlets are not the only sources of food; they only supply the food that is eaten 'at home', whereas the food service sector supplies all the food that is eaten 'away from home'.

The away from home market includes take-away food, food eaten in restaurants and pubs as well as institutional food such as in schools, hospitals and other government organizations. Some of these specialize in organic food, such as an organic restaurant or pub, or include a particular organic item on their menu, such as organic beef.

Although the national profile of food distribution is of interest, food is purchased by individuals who live and work in a particular area with its own, often with a somewhat unique, character. Thus, there are regional differences in where food is purchased and what food is available. Hence, individuals, as long as they have the financial capacity and a car, are confronted with an array of choices, often of bewildering proportions, but they are still limited by what is made available to them in their immediate surroundings.

Research on Organic Consumers

The fact that organic food exists and is available for consumers is as a result of a long series of events generally thought to have commenced during the 1940s and 1950s. There were separate initiatives in different countries. These included 'ecological agriculture' in Switzerland, which is associated with the writings of the Muellers, Rudolf Steiner's teachings on 'biodynamic agriculture' in Germany and Austria, Jerome Rodale's writings on soil and health in the USA, and Albert Howard and Eve Balfor's work in the UK on what came to be known as 'organic farming'. During this time, numerous organizations were formed, many of which still exist today. These include charities such as Garden Organic and the Soil Association, the latter being the largest certifier of organic products in the UK.

The development of the organic movement continued during the 1960s and 1970s when there was increasing consumer activism associated with concern about man-made changes to the natural environment. This era is perhaps epitomized in the work of Rachael Carson and her evocatively titled publication 'Silent Spring'. During this time, the International Federation of Organic Agricultural Movements (IFOAM) was formed and has continued to provide a forum for the global coordination of the movement. However, it was not until the 1990s that organic received formal recognition as a food production system by many national governments. It was at this point that it started to move from the fringe into a significant activity in the mainstream food industry. In addition to arriving on the list of possibilities for the mass population, academic research on the organic sector also started to appear. There is now a significant body of international research which includes comparisons of many facets of organic farming, including crop production, biodiversity benefits and soil health[15,16] as well as research on the demographics and motives of organic consumers[2]. The latter paper provides a comprehensive review of the complexity of this type of research and the specific contributions from major studies that have explored the reasons why consumers purchase organic food, as well as their demographic profile. Both of these will be reviewed prior to considering what organic food is actually purchased.

Why do people buy organic food?

The consensus of international research provides a very clear picture of the reasons why people buy organic food. Although there may be differences in the ranking of the

important issues due to the specific cultural and demographic factors, the main reasons, in order of priority, are: personal health; product 'quality'; and concern about degradation of the natural environment. These were identified some time ago[17] and have consistently been supported by subsequent research[2,18].

Although consumers consistently cite health as a reason for purchasing organic food, this perception is not consistently supported by scientific research[19,20]. The Food Standards Agency in the UK has recently reported on a meta-analysis of the scientific evidence that examines the potential human health benefits from consuming organic food[21]. The main issue under investigation in this report is whether there are measurable benefits from consuming organic food. The benefits of organics are considered to be the vitamins, minerals and other health-giving properties that they embody, whereas the perceived negative aspects of non-organic food include the presence of artificial chemicals used in the production, processing and storage of the product. Although it is considered to be contentious, this report concluded that there is currently 'no evidence of a health benefit from consuming organic compared to conventionally produced foodstuffs'[21] (p. 2). The research linking organic food composition to direct health benefits tends to be inconclusive partly because of the difficulty of undertaking this type of research. The confounding issues include the greater intrinsic variability in organic systems, which make it difficult to draw conclusions from short-term comparisons of paired organic and non-organic farms. As a consequence, production systems often need to be monitored at the same sites over a number of years to achieve significant results[16,22]. Furthermore, the specifics of the actual management or husbandry *per se,* rather than the strict adherence to the requirements of organic certification can have a major influence on the quality of the organic product[23]. And finally, different crop varieties vary in their response to different environmental conditions—the Genotype by Environment ($G \times E$) effect[24]—which also influences product quality and is substantially independent of the type of production system, whether organic or otherwise.

Further to the variation in the health-enhancing aspects of the content of organic products, there are issues in relation to other aspects of an individual's diet. For example, even if the organic food has higher levels of the positives, an increase in their consumption will not necessarily add to an individual's health if one already has them in sufficient proportion. On the other hand, just because a chemical is artificial, or man-made, does not automatically mean that it is dangerous to human health; there are many chemicals that occur naturally that are extremely toxic to humans. Also the level of chemicals in all food products is strictly monitored by the national governments in most countries through a system of maximum residue levels (MRLs). Although organic food may have lower MRLs for many chemicals, there is minimal evidence to suggest that this is necessary for human health.

The health motivation can be seen as a proactive measure, or as a reaction to an adverse situation. A proactive purchaser would be someone who believes that organic food is healthier, and that these foods can have an impact on their health. One example would be when the parents of babies and young children, often concerned about 'pure' and 'natural' foods, become interested in organic food. In a similar manner, health as a purchase motivator has been found to take on greater significance as people age[25]. Others purchase organic food as a reaction to an adverse situation. For example, they may be faced with a serious illness and in the journey of exploring treatments for their condition they turn to organic food in the belief that it will aid their recovery.

The second important issue is quality. The product quality parameters that consumers generally relate to organic food, particularly fresh fruits and vegetables, include that it tastes better and that the supply chain delivers a fresher product[3]. But the quality of a particular product is subject to many variables. Hence, product quality is problematic as it varies according to the individual consumer's expectations and this often relates to a particular product, purchased at a particular time and for a particular use. Thus, in a manner similar to health as previously discussed, the link between any production system, organic or otherwise and product quality is tenuous.

And finally, the third major reason mentioned for purchasing organics is concern for the environment. There is evidence to support the fact that organic farming is less damaging on the natural environment[15,16]. Indeed, the environmental benefits of organic production methods are the rationale given by the government in the UK for providing additional financial assistance to organic farmers[26].

The other less commonly mentioned reasons why people buy organic food include animal welfare[27–30] and fashion[2,31]. Concern about animal welfare is more important for particular organic products and countries where intensive animal farming systems are commonly used. This includes chicken meat and eggs, pork products and, to a lesser extent, beef and dairy products.

Who buys organic food?

From some perspectives, the results from the past 20 years of investigation into who buys organic food have been disappointing. The desire to identify the characteristics of organic food buyers within the mass market is understandable and the majority of the literature has concerned itself with demographics as a segmentation variable; however, from this perspective, a clear profile has remained elusive. This research indicates that organic food buyers exist across all demographic segments, with some small trends being evident. In particular, they may have higher levels of education, be more affluent, be women and have young children. In addition, they may be more likely to grow some of their own fruits and vegetables, and be

vegetarian[32]. As one report pointed out '... focus group study confirms that only looking at gender, income, education, and family/household size may yield contradictory results because people's motivations are complex'[33] (p. 392). Hence, it is relevant to look to other ways of identifying organic food buyers.

Some studies have used multiple segmentation parameters. These include combinations of attitude and behavior, which resulted in segments based on their level of 'green' purchasing behavior—from indifferent to very green. Other examples of behavioral segmentations include those based on the level of awareness—unaware, aware non-users and aware users[34] or level of commitment—complacent, conceivable and committed[35]. Another segmentation variable is that of purchase frequency—ranging from heavy to light users. For example, in the UK, around 70% of buyers claim to purchase organic food; however, with annual sales of £2 billion[36] which equates to a market share of around 1.5%, it is obvious that only a very small proportion, much less than 1%, buy a large quantity on a regular basis and hence most only buy small amounts on an irregular basis. Thus, the majority of consumers move between organic food and its conventional counterpart and have been labeled as switchers[37].

There are some important methodological issues that have hampered the usefulness of this segmentation research. One issue is that of the choice of retail outlet which 'is a critical variable in explaining purchases of organic foods'[38] (p. 1115). For example, the products available in a supermarket tend to differ from those in a food cooperative. It is important to recognize that food consumers often use more than one retail outlet. For instance, on a weekly basis, they may have a delivery from an organic vegetable box scheme, go to a food cooperative and then fill all the missing purchases on a trip to the supermarket. Thus, consumers go through a two-stage decision process, first they select a retail outlet, and it is only when this choice is made that they make the second choice that of deciding between organic and conventional products. And importantly, their choice is always limited by what is available to them, which, in relation to individual products, is referred to as 'choice editing' by retail outlets[39].

Another methodological issue is that most of the research is based on buyers' self-reporting of what they think they purchase, or on their intentions in relation to future purchases, both of which are notorious for being inaccurate. A gap has been identified between positive attitudes toward organic food and actual purchase behavior[30]. This gap was explored by others[40] who concluded that consumer decision-making is extremely complex and that further research is needed to explore the trade-offs that they make. Consequently, a positive attitude toward organic food does not necessarily translate into purchases of it. Perhaps this is because some people want to be healthy and do the 'right' thing but forfeit this as they are unable to justify the higher price and reduced choice of many organic products, and hence conventional food is given priority in their busy lifestyle. Some research has explored how this gap could be closed by investigating the reasons why consumers do not purchase organic food. Again there is a general consensus in the literature with the main deterrents being its generally higher price and its limited availability[2].

What organic food is bought?

Research investigating the actual purchases of organic food has confirmed that there is a significant gap between stated and actual buying behavior. Research from Germany[41] compared what organic food consumers thought they purchased, based on self-reporting questionnaires, with what they actually purchased, based on supermarket scanner information. In addition to confirming that there is a gap between what buyers say they do and what they actually do, the results identified an unexpected trend. Buyers who purchase organic products more often (such as several times per week) are likely to understate their purchase frequency (11% stated compared with 18% actual). In contrast, those who purchase less frequently (such as once a month) are more likely to overstate their purchase frequency (19% actual compared with 11% stated).

This identification of actual purchases of organic food has been facilitated by recent developments with the use of barcode technology combined with customer loyalty cards. Historically, organic food was only available in selective locations, such as health food stores. However, supermarkets have gradually increased their number of organic product lines in response to changing consumer preferences and the development of the organic supply chain. Now it is possible to purchase an organic variant for nearly all products in most supermarkets in developed countries. Further, an individual's actual purchases can be collected by monitoring the product barcodes at the checkout and linking this to their loyalty card. Although this is a massive improvement in terms of understanding organic food consumers, it does not capture the full picture. This information does not include food purchased outside the supermarkets, such as from complementary retail outlets, nor does it capture purchases from the food away from home sector, some of which may be organic. These limitations are in addition to the fact that some supermarket shoppers do not have loyalty cards, many of whom are likely to be organic food buyers.

A recent report[42] provided an insight into organic fresh fruit and vegetable purchases in one leading UK supermarket chain. Fruits and vegetables are extremely important to the organic sector. In addition to being a key gateway product (i.e. the first organic product purchased by many consumers), they also have the largest share of any product category. For this supermarket, they accounted for around one-third of all their organic food sales.

These findings[42] support other research which states that the majority, in this case 75%, of customers purchase

organic products. However, only a small proportion of these customers account for majority of the sales. In another report[26] it was stated that 84% of the sales of organic products come from only 23% of customers. These results are remarkably consistent with the Pareto Principle, or 80/20 rule, which, when applied to business, states that the majority of sales will come from a minority of customers. Thus, organic fresh fruit and vegetable purchases are not habitual for most customers as they only make sporadic purchases and hence, as previously mentioned, are seen as switchers. Moreover, organic consumers are 'hampered by the lack of consistent, objective (scientific) evidence of the benefits (taste, health, environment) which leaves the majority of consumers at best confused and at worst sceptical'[42] (p. 6).

In another recent report[43], the Lifestyle of Health and Sustainability (LOHAS) profiling was used to create segments in the organic food market ranging from Leaders through to Learning, Learners and finally Laggards. These intuitively appealing descriptions were used for exploring who purchased what organic food from where, and identified, among other things, that most Leaders purchase organic products in complementary retail outlets whereas those in the Learning category use supermarkets.

Hence, while these research reports continue to contribute to our understanding of those who buy organic products, a comprehensive profiling of these buyers remains elusive. Although organic food comes from a clearly identifiable production system, and this fact is communicated to consumers via product labels, its uniqueness is not dominant in the context of food purchase decisions, which involve complex trade-offs among numerous product attributes. Thus, the choice of any food type, including organic, 'is a complex issue that is unable to be explained using a single variable'[44] (p. 139).

Conclusion

The challenge of understanding the complexity of organic food consumers has benefited from numerous research activities. There is a general consensus in the literature on the reasons why people buy organic food. These have remained stable over time, and, although there are some slight differences between countries and for particular products, the main reasons, in order of priority, are: issues associated with personal health; product 'quality'; and concern about degradation of the natural environment. However, interestingly, there is a gap between consumer perception of the superior health features of organic food and the scientific evidence. There is also a gap between those consumers who have a positive attitude toward organic food and their relatively low level of actual purchases. Again, there is a general consensus that this is because of the higher price and limited availability of organic food. The results from investigations into who buys organic food have been disappointing, as they remain elusive to the commonly used market segmentation tools such as demographics. However, research has identified that most consumers buy organic, but only some of the time, and hence they switch between organic and conventional on a regular basis.

A new contribution to our understanding of organic food consumers is emerging from research that captures actual purchases in supermarkets by linking barcode information to customer loyalty cards. These results highlight the errors inherent in research that relies on consumer self-reporting methodologies while they do provide support for other important issues. They show that fresh fruits and vegetables have a relatively high market share that is well above the average of all organic products and, with continuing relatively higher growth rates, this is likely to continue. They also show that a relatively small number of products make up a large percentage of sales, as well as supporting the suggestion that only a relatively small number of consumers purchase on a regular basis. Thus, as previously mentioned, most organic consumers are switchers.

In conclusion, consumer research remains a fertile area for further investigation as researchers grapple with its inherent complexity. And organic food does not appeal to a coherent segment of the market as 'beyond the two poles of the converted (regular consumers) and the sceptical non-consumers who would never consider buying organic, there is a large body of consumers who buy organic food on a more occasional basis, but lack the knowledge, financial resources, conviction, or simply the inclination to buy more regularly'[40] (p. 623). With this in mind, further research on the role that food plays in consumers' lives, along with investigating their purchase context, is required to complete our understanding of organic food consumers.

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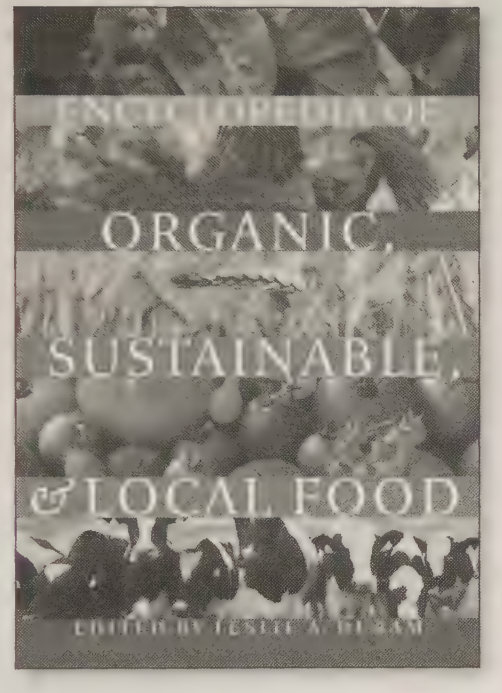

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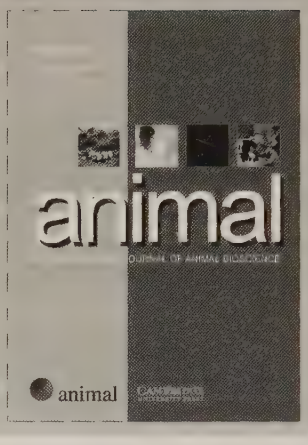

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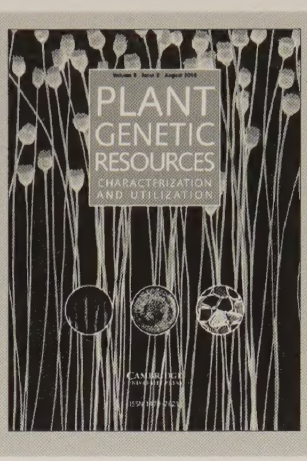

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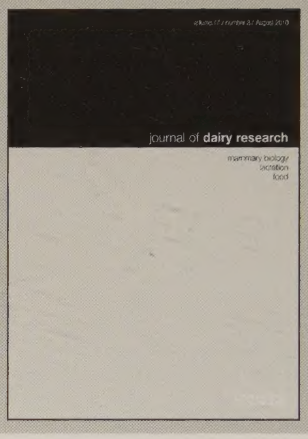

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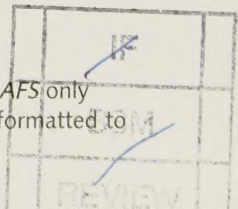

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